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A SERIES OF TEXTBOOKS FOR PERSONS ENGAGED IN THE ENGINEERING PROFESSIONS AND TRADES OR FOR THOSE WHO DESIRE INFORMATION CONCERNING THEM. FULLY ILLUSTRATED AND CONTAINING NUMEROUS PRACTICAL EXAMPLES AND THEIR SOLUTIONS

TELEPHONY

404

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PREFACE

The International Library of Technology is the outgrowth of a large and increasing demand that has arisen for the Reference Libraries of the International Correspondence Schools on the part of those who are not students of the Schools. As the volumes composing this Library are all printed from the same plates used in printing the Reference Libraries above mentioned, a few words are necessary regarding the scope and purpose of the instruction imparted to the students of—and the class of students taught by—these Schools, in order to afford a clear understanding of their salient and unique features.

The only requirement for admission to any of the courses offered by the International Correspondence Schools is that the applicant shall be able to read the English language and to write it sufficiently well to make his written answers to the questions asked him intelligible. Each course is complete in itself, and no textbooks are required other than those prepared by the Schools for the particular course selected. The students themselves are from every class, trade, and profession and from every country; they are, almost without exception, busily engaged in some vocation, and can spare but little time for study, and that usually outside of their regular working hours. The information desired is such as can be immediately applied in practice, so that the student may be enabled to exchange his present vocation for a more congenial one or to rise to a higher level in the one he now pursues. Furthermore, he wishes to obtain a good working knowledge of the subjects treated in the shortest time and in the most direct manner possible.

In meeting these requirements, we have produced a set of books that in many respects, and particularly in the general plan followed, are absolutely unique. In the majority of subjects treated the knowledge of mathematics required is limited to the simplest principles of arithmetic and mensuration, and in no case is any greater knowledge of mathematics needed than the simplest elementary principles of algebra, geometry, and trigonometry, with a thorough, practical acquaintance with the use of the logarithmic table. To effect this result, derivations of rules and formulas are omitted, but thorough and complete instructions are given regarding how, when, and under what circumstances any particular rule, formula, or process should be applied; and whenever possible one or more examples, such as would be likely to arise in actual practice —together with their solutions—are given to illustrate and explain its application.

In preparing these textbooks, it has been our constant endeavor to view the matter from the student's standpoint, and to try and anticipate everything that would cause him trouble. The utmost pains have been taken to avoid and correct any and all ambiguous expressions—both those due to faulty rhetoric and those due to insufficiency of statement or explanation. As the best way to make a statement, explanation, or description clear is to give a picture or a diagram in connection with it, illustrations have been used almost without limit. The illustrations have in all cases been adapted to the requirements of the text, and projections and sections or outline, partially shaded, or full-shaded perspectives have been used, according to which will best produce the desired results. Half-tones have been used rather sparingly, except in those cases where the general effect is desired rather than the actual details.

It is obvious that books prepared along the lines mentioned must not only be clear and concise beyond anything heretofore attempted, but they must also possess unequaled value for reference purposes. They not only give the maximum of information in a minimum space, but this information is so ingeniously arranged and correlated, and the indexes are so full and complete, that it can at once be made available to the reader. The numerous examples and explanatory remarks, together with the absence of long demonstrations and abstruse mathematical calculations, are of great assistance in helping one to select the proper formula, method, or process and in teaching him how and when it should be used.

The numerous questions and examples, with their answers and solutions, which have been placed at the end of each volume, will prove of great assistance to all who consult the Library.

The present volume is devoted to telephony. The entire field has been thoroughly covered and the utmost pains have been taken to treat the subjects in a manner most useful to those engaged in telephone exchanges and manufacturing companies. The treatment is such as will give the practical man enough of the theory to enable him to handle intelligently any difficulty that he is apt to encounter in his line of work. The testing of telephone apparatus, circuits, and lines, the splicing and testing of cables, and overhead and underground construction work have been fully treated. American telephone systems and apparatus, including those used by both the Bell and the so-called independent companies, have been carefully explained. American telephone practice is acknowledged to be in advance of that in any other country; consequently a thorough discussion of American practice and of the fundamental principles upon which it is based, such as is contained in this volume, makes it by far the most complete treatise on the subject that has yet appeared in print.

The method of numbering the pages, cuts, articles, etc. is such that each subject or part, when the subject is divided into two or more parts, is complete in itself; hence, in order to make the index intelligible, it was necessary to give each subject or part a number. This number is placed at the top of each page, on the headline, opposite the page number; and to distinguish it from the page number it is preceded by the printer's section mark (§). Consequently, a reference such as § 16, page 26, will be readily found by looking along the inside edges of the headlines until § 16 is found, and then through § 16 until page 26 is found.

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CONTENTS.

Principles of Telephony Pamphlet

TELEPHONY. 792

(PART 1.)

ACOUSTICS.

1. Acoustics is that branch of physics which treats of the phenomena and laws of sound and sound waves.

SOUND.

2. Definition.—There are two distinct definitions of sound: First, *sound* is the sensation which is perceived when the nerves of hearing are properly excited; and, second, *sound* is a physical disturbance capable of producing on the auditory nerves the sensation of hearing.

According to the first definition, therefore, sound is the sensation itself, while according to the second, it is the stimulus or cause of the sensation. The word sound will be used in this treatise according to both these definitions, proper care being taken, however, to prevent any likelihood of confusion between the two.

WAVE MOTION.

3. The physical disturbance capable of exciting the auditory nerves is a wave motion passing from some vibrating body through some material medium, which is usually air, though it may be any gas, solid, or liquid. It is well established that all action between points or bodies separated by space is due to vibrations of the medium filling this space, no matter what that medium may be. In the phenomena of light, heat, or electricity, the medium is the ether; while in the case of sound, some more tangible medium, such as a gas, liquid, or a solid, is needed.

SOUND WAVES.

4. Vibrating Diaphragm.—In order to understand more clearly the nature of the propagation of sound waves

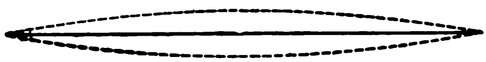

FIG. 1.

in any substance, those set up by a vibrating diaphragm, such as is shown in Fig. 1, will be considered. This dia-

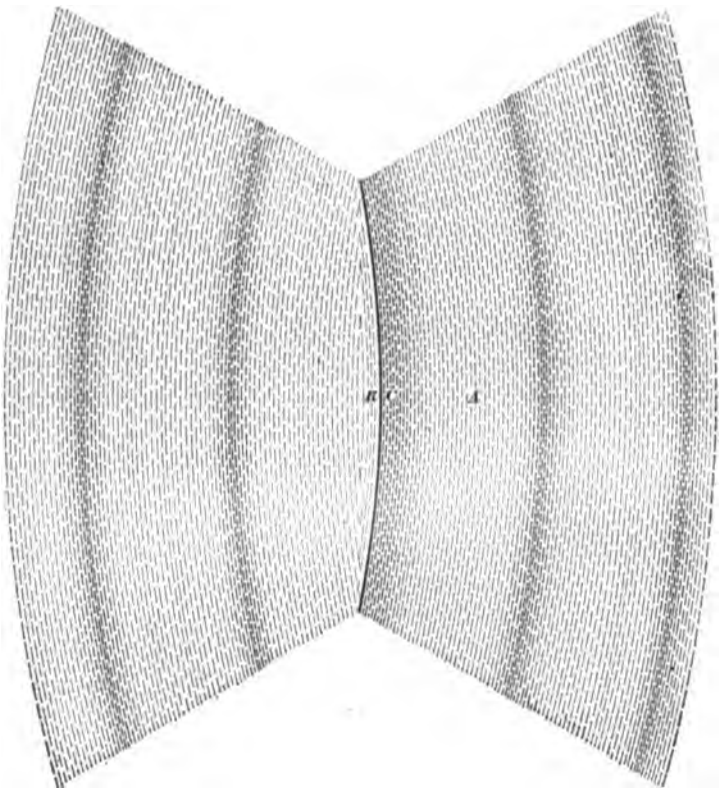

FIG. 2.

phragm is supposed to be of some thin elastic substance, such as sheet iron, and to be firmly supported at its edges.

It is supposed, moreover, that it is maintained by some means in a constant rapid vibration to and fro between the limits indicated by the curved dotted lines.

As it moves to the right, there is produced a condensation of the atmosphere immediately in front of it at *C* and a rarefaction immediately in the rear of it at *R*, as indicated in Fig. 2. The condensation at *C* is communicated to the particles of air at the right of *C*, and by them to the particles of air at their right, and so on. A wave of condensation therefore travels to the right through the air, gradually diminishing in intensity until it is finally lost. When it moves back to the left, the plate causes a rarefaction at *C*, and the particles of air from *A* rush into it, thus causing a rarefaction at *A*, which in turn is filled by particles in the space at its right. Thus, a wave of rarefaction follows the wave of condensation, and this in turn is followed by another wave of condensation, and so on as long as the plate continues to vibrate. A similar set of waves, but in reverse order—i. e., a wave of condensation following a wave of rarefaction—is also sent out in the opposite direction by the other side of the plate.

5. Movements of Particles in Wave.—Consideration will show that while the wave travels outwards from the diaphragm, the particles of air through which the wave is propagated move only to and fro in a comparatively limited path. A similar action takes place when a pebble is dropped into a pond of still water. Waves are set up which proceed in the form of circles, of which the point where the pebble entered the water is the center. The wave undoubtedly travels over the surface of the water; but by observing small chips floating on the water, it will be seen that they move only up and down when acted upon by the wave. So it is with the particles of air or of any other medium through which wave motion is being transmitted. In the case of sound waves, the to-and-fro motion of the particles of air is in the direction of the line of propagation of the wave itself, while in the case of the ripples on the water, the to-and-fro motion of the various particles of water is at right angles to the line of propagation of the wave.

6. Graphical Representation.—A vibrating body, such as a tuning-fork, will send out waves in the air which follow each other in regular succession. These waves may

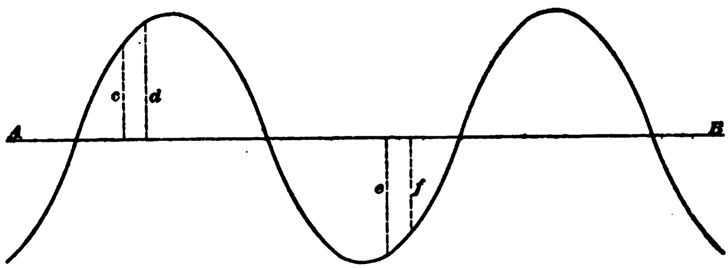

FIG. 3.

be represented graphically as in Fig. 3. Consider the wave to be moving in the direction of the line *A B*, then the displacement of a particle of air at any point in the wave will be represented by the length of the dotted lines *c*, *d*, *e*, *f*, etc.; i. e., the particle has moved that far from its normal position of rest.

In order that the curve may be readily comprehended, the amount of the motion of the particles, or their displacement from their position when at rest, is represented as being at right angles to the line *A B*, although the particles are really vibrating to and fro in the direction of this line.

THE EAR.

7. If these waves originate in or are communicated to the medium in which the ear is situated, then at each recurring condensation the elastic membrane called the **tympanum** or **drum** of the ear will be pressed inwards, and at each recurring rarefaction will be drawn outwards. These vibrations will be transmitted by means of a chain of bones, termed the **hammer, anvil,** and **stirrup,** to the membranous wall that closes an internal cavity, called the **vestibule,** through it and some canal-like passages filled with a liquid and containing ramifications of the auricular nerve, which the vibrations finally reach and excite. This nerve ends in minute rods or fibers, each of which seems to vibrate at a definite frequency, and each one is excited only by a wave having the same period of vibration.

The greater the degree of condensation and rarefaction of the medium in a given time, the greater will be the motion of the drum of the ear, and, consequently, of the mechanism of the ear which acts upon the nerves. Hence, it follows that the function of the human ear is the mechanical transmission to the auricular nerve of each expansion and contraction which occurs in the surrounding medium, while the function of the nerve is to convey to the brain the sensations thus produced. From the above, one can understand why it is possible to make some persons who are deaf on account of an unnatural condition of some part of the ear mechanism hear by the use of apparatus which collects and transmits sound vibrations through the teeth and bones in the head to the auricular nerve. The nerve itself must, of course, in order to accomplish this, be in a natural state, free from disease.

SIMPLE HARMONIC MOTION.

8. Such a curve as that shown in Fig. 3 represents what is termed *simple harmonic motion*, which is a most important form of vibration, not only in acoustics, but in all other branches of physics relating to wave motion. If a pinhead p' (Fig. 4) on a disk D revolving at a uniform speed is allowed to cast a shadow perpendicularly on a plane at right angles to the disk, the movement of this shadow will be a simple harmonic vibration. The movement, of course, will be in a straight

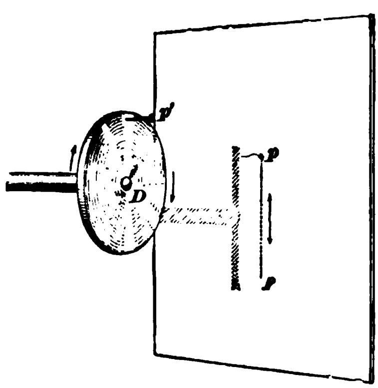

FIG. 4.

line, as shown at pp. Starting at one end of its path, the shadow will move slowly at first, but with increasing velocity, until the middle point of its path is reached. Here the velocity will be a maximum, and after passing this point, it will decrease more and more rapidly until it comes to rest at the other end of the path. The direction of motion will then be reversed, and the shadow will again attain its maximum velocity in the other direction at the center point in its path, and will again come to rest momentarily at the starting-point.

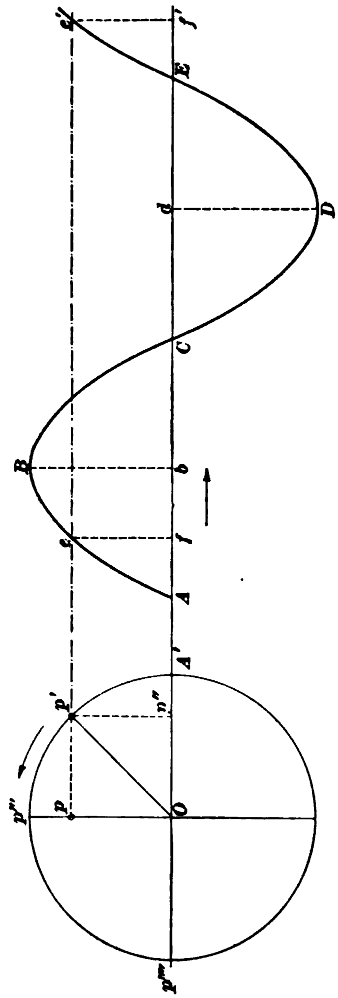

FIG. 5.

9. Simple harmonic motion may be defined as the movement of the projection on a fixed straight line of a point moving uniformly in a circular path. This definition will perhaps be made clearer by considering Fig. 5. Let p' be a point moving with a uniform velocity in a circular path of which the center is O, the direction of motion being as indicated by the curved arrow. The projection p of the point on the vertical diameter of this circle will, it is evident, move from one end of this diameter to the other in exactly the same manner as did the shadow of the pin-head in Fig. 4. If, while the projected point p is moving along the vertical diameter with harmonic motion, it should be caused to trace its course on a sheet of paper by drawing the paper with a uniform motion from right to left under the point, the path on the paper would be as indicated by the curved line. The beginning A of the curve corresponds to a time when the point p' was at the point A' on the circumference. As the movement progresses, the curve will gradually rise to a maximum height at B, which is reached when the point p' has been rotated from its original position A' through 90° of the circle to its highest position p'''. The curve will then descend and reach the zero line at C, when the point p' has been rotated through an angle of 180° to p''''. The next half of the revolution of the point p' will cause its projected point p to trace a curve below the line exactly similar to that traced by the first half above the line.

10. Amplitude.—The amplitude of vibration is the maximum displacement of the point p from its center position O. Thus, in Fig. 4 the amplitude would be represented by one-half the length of the line $p\,p$, and in Fig. 5 by the radius of the circle.

11. Cycle.—A complete vibration to and fro of the point p, corresponding to a rotation of the point p' through 360°, is termed a cycle. A complete cycle would therefore be represented by the part $A\ B\ C\ D\ E$ of the curve, $E\ e'$ being part of the next cycle. It is seen that in its vibration the point p in Fig. 5 has completed one full cycle and has started on the next, being at the time shown at the point e' on the curve. The distance $A\,E$ is the length of one complete wave, and is called the wave length.

It is evident that simple harmonic motion, although taking place in a straight line, is very closely allied to circular motion, and it is therefore customary to deal with it by means of angular measure. Thus, a complete cycle would be represented by 360°, or by $2\,\pi\,r$, where r is the radius of the circle, or the amplitude of vibration.

12. Phase.—The portion of a cycle through which a vibrating point has passed at a given time is called the phase of the vibration, and is usually expressed in angular measure. Thus, the point B on the curve in Fig. 5 represents a phase of 90°; the point C a phase of 180°; the point D, 270°; and the point E, 360°, or a complete cycle.

13. Frequency.—The number of complete cycles occurring in one second of time is called the frequency of the vibration. The term frequency is often misused by representing it as the number of half vibrations that occur in a second.

14. Period.—The period of a vibration is the time that elapses during one complete cycle; thus, if P represent the period and n the frequency, it is evident that $P = \frac{1}{n}$. It is the time required for the wave to move from A to E in Fig. 5.

The horizontal distance measured along the line $A\,E$ in Fig. 5 may be taken as a measure of the time elapsing during the passage of the point p from any point on the diameter of the circle to any other point, or it may be taken as a measure of the angle through which the point p' has rotated from its original position A'. Thus, if it takes the point p just four seconds to pass from the center point O through a complete cycle back to that point, it is evident that the distance $A\,E$ will represent the time of one complete cycle, that is, four seconds. It may also represent the angular rotation of the point p', and in circular measure would be 360° or $2\pi r$. In a like manner, the distance $A\,b$ would represent a time of one second, since it is $\frac{1}{4}$ of $A\,E$, or an angular rotation of 90°; the distance $A\,C$ a time of two seconds, or an angular rotation of 180°; and the distance $A\,d$ a time of three seconds, or an angular rotation of 270°.

THE CURVE OF SINES.

15. The curve shown in Fig. 5, which is used to represent simple harmonic motion, may also represent all the values of the sine of an angle, while the angle is uniformly increasing from 0°, and is therefore termed the curve of sines, or the sine curve.

It has been shown that the distances from the point A in a horizontal direction may be considered as measures of the angle through which the point p' and the line $O\ p'$ has rotated. In a similar manner, it may be shown that the ordinate of the curve at any point, that is, the perpendicular distance from the curve to the base line, is a measure of the sine of the angle represented by the horizontal distance of that point from the reference point A, for

$$\sin A'\,O\,p' = \frac{p'\,p''}{O\,p'},$$

or

$$p'\,p'' = O\,p' \sin A'\,O\,p' = r \sin A'\,O\,p',$$

where r is the radius of the circle, or the amplitude of vibration.

Now, $p'\,p'' = O\,p$, and as any ordinate $e\,f$ at any point on the curve is always equal to the distance $O\,p$ for the corresponding angle, it follows that any ordinate on the curve will be

$$e\,f = r \sin A'\,O\,p',$$

where $A'\,O\,p'$ is the angle corresponding to the position taken on the curve.

COMPLEX WAVE MOTION.

16. Even though the vibrations of a point may be periodic, that is, regularly recurring, they may not follow such a simple law as that of simple harmonic motion. A vibration which is not harmonic is represented by the curve A in Fig. 6, and this wave may be considered as the resultant of two sine waves B and C, of which C has twice as great a frequency as B. It is readily seen from the curves that C makes just twice as many complete vibrations in a given time as B. The curve A is obtained by adding together the ordinates of the curves B and C; thus the ordinate $a\,d$ of the point a on the curve A is the sum of the ordinate $c\,d$ of the curve C and the ordinate $b\,d$ of the curve *B*. When the curves *B* and *C* are on the opposite sides of the zero line, the difference of the two ordinates is taken. Thus, the point *a'* on the curve *A* is determined by subtracting the ordinate *c' d'* of the curve *C* from the ordinate *b' d'* of the curve *B*. The curve *A* is called the resultant of the curves *B* and *C*.

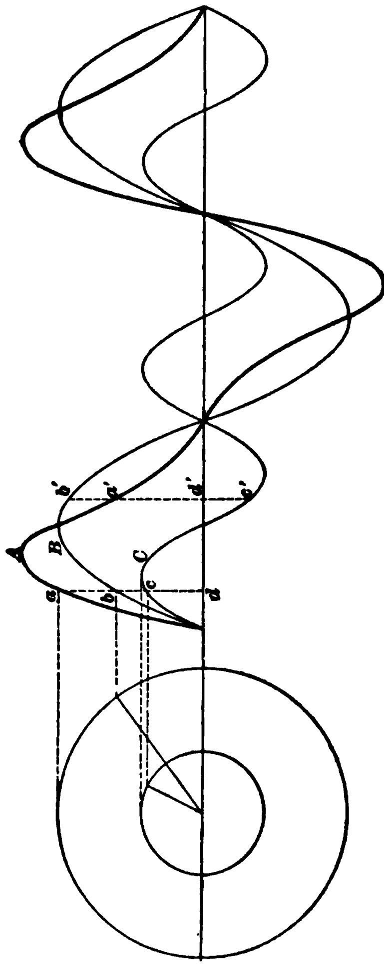

FIG. 6.

17. Fourier's Theorem.—This theorem states that any complex periodic vibration may be considered as the resultant of a number of simple vibrations, of which the frequencies are 1, 2, 3, 4, etc. times the frequency of the complex vibration. This is well illustrated in Fig. 6, where, as we have seen, the curve *A*, representing a compound vibration, is composed of two other curves representing simple vibrations, one of which has a frequency the same as that of the compound vibration, and the other of which has a frequency equal to twice that of the compound vibration.

THE LIMITS OF AUDIBILITY.

18. All vibrations that set up waves in the manner already mentioned are not capable of producing the sensation of sound.

A uniform series of vibrations, a definite number of which are produced in a given time, and which are within limits capable of exciting the auricular nerves, is called a tone. Thus, a simple musical tone results from a continuous, rapid, and uniformly recurring series of vibrations, provided the number of complete vibrations per second falls within certain limits.

If, for example, the vibrations number less than 32 per second, a series of successive noises are heard, while, if their number is greater than 40,000 per second, the ear is not capable of appreciating the sound. Of course, different people have very different powers of hearing. The number of vibrations of a musical tone is somewhere between 35,000 and 32 per second, and the number of vibrations produced by the human voice when talking is between 61 and 1,305 per second. In ordinary conversation, the average frequency is about 300 per second.

CHARACTERISTICS OF SOUND.

19. All sounds have *three characteristics*, variations in which enable us to distinguish between the different sounds we hear. They are termed loudness, pitch, and timbre.

20. Loudness. — Loudness is that characteristic of sound which depends on the *amplitude* of the sound wave. It depends on the amount of energy in the vibrations producing the sound. As an illustration, the striking of a certain key on a piano may be made to produce a loud or a soft sound, according to the degree of force with which the key is struck. If considerable energy is used in striking the key, the corresponding string is made to vibrate with great amplitude, and therefore to give forth a sound of great loudness. The pitch and timbre are the same, whether the key is struck forcibly or lightly. Loudness is the intensity of sound.

21. Pitch.—Pitch depends *entirely* on the *number* of *vibrations per second*, that is, upon the frequency. A low rate of vibration produces what is called a low tone and a high rate a high or shrill tone. The difference between the sounds emitted by long and short strings of the same material and of equal size and tension is one of pitch. This is well illustrated in the violin, where the same string may be made to give forth a low or a high tone by merely varying the effective length of the string by pressing the finger against it at different points. Such a vibration as is illustrated by curve *B* in Fig. 6 would produce a sound of a certain pitch, while the wave motion represented by curve *C* in the same figure would produce a tone of twice the pitch, because its frequency or rate of vibration is twice as great as that of the wave *B*. The fact that the frequency of the wave represented by *C* is just double that of the wave represented by *B* would render the tone set up by the former the octave of the latter.

22. Timbre.—Timbre is the quality of sound, and depends only on the *form* of the *sound wave*. A pure tone is one produced by a simple vibration such as is represented in Fig. 3. Such a tone has a very different sound from one produced by a more complex set of vibrations, as, for instance, those represented by curve *A* in Fig. 6. This curve, as we have seen, is produced by a combination of two simple wave motions, one represented by *B* having the same frequency as that of the curve *A* itself, and the other represented by *C* having double that frequency. The waves of ordinary musical tones are rather more complex than that shown by *A* in this figure, and are usually composed of one simple vibration having the same frequency as that of the complex tone when considered as a whole, and also many other vibrations having frequencies of 2, 3, 4, etc. times the frequency of the first vibration. The wave having the lowest rate of vibration is termed the fundamental wave of a composite sound, and those waves of higher rates of vibration are called overtones. These latter are due to the fact that the body producing the sound vibrates not only as a whole, but in its various parts, the vibration of the parts of course being of a higher frequency than those of the whole. The timbre or quality of a sound depends not on the amplitude of vibration as does the loudness, nor on the rate of vibration as does the pitch, but on the number of overtones superimposed upon the fundamental tone and also on the relative intensities of the vibrations of the overtones to each other and to that of the fundamental. The quality of a tone may therefore be said to depend on the form of the resultant wave.

23. Phase Relation and Wave Form.—To illustrate the effect which the phase relations of the various components of a complex sound may have upon the timbre or quality, reference is made to Fig. 7. In this are shown three complex waves A, A', and A'', each of which is composed of two simple waves B and C, as in Fig. 6. The component waves B, B, B are in each case alike in amplitude and frequency, as are also the component waves C, C, C. The frequency of waves C is, however, twice that of waves B. Although having the same components, the form of the resultant wave is entirely different in each of the three cases, this difference being due to the fact that the two component curves differ from each other as to their phase relations in each case. Thus, in curve A, the component curve C always passes through the zero line at the same instant as does the component curve B. In the curve A', the curve C is shifted about thirty degrees (in relation to curve B) to the left of the position which it occupied in curve A, i. e., one-sixth of its own wave length; and in curve A'', the curve C is again shifted to the left by about an equal amount. The sounds produced by the three wave forms A, A', and A'' would differ not much as to loudness, for their amplitudes are about the same; not as to pitch, for their frequencies are the same; but as to timbre, because the wave forms are different. The changes in the form of a resultant wave, brought about by shifting the phases of its component parts with respect to each other, is much more apparent where a larger number of components than two is considered. As a familiar illustration of differences in timbre, the same note on the flute, the violin, and the clarinet may have identically the same loudness and also the same pitch, yet the tones will be very different. The note

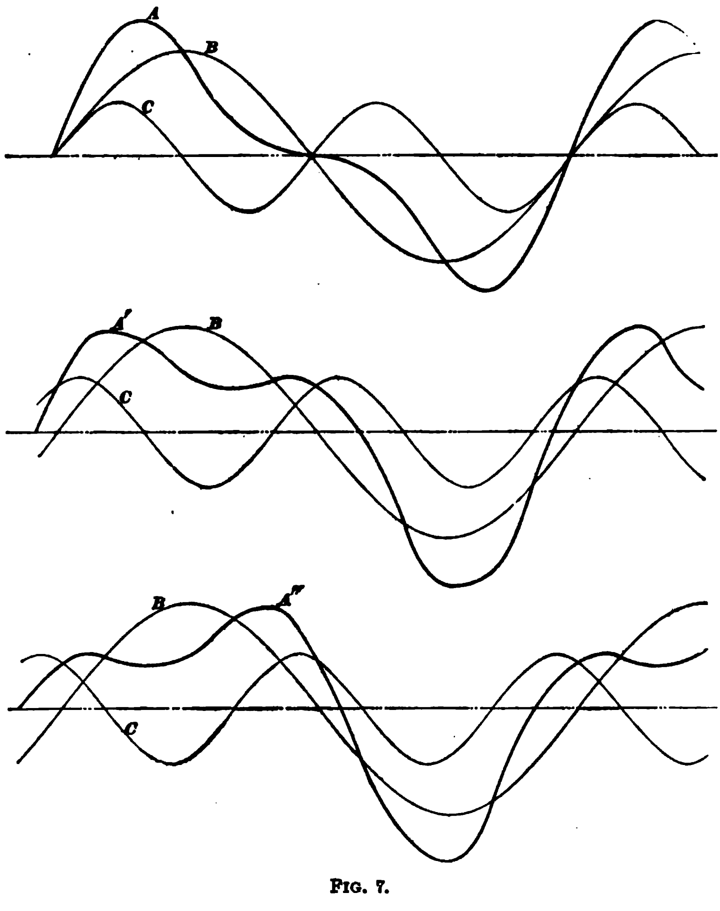

FIG. 7.

sounded on the violin differs from the same note on the flute, because, although the fundamental of both may be the same in pitch and loudness, yet the overtones, or, as they are sometimes called, the harmonics, differ both in number and relative intensities. What is recognized by the ear as the pitch of such sounds is in reality the pitch of only one of these tones, that is, the fundamental, because it is usually the most prominent. This difference in the above two sounds is due to timbre alone.

ARTICULATE SPEECH.

24. The successive vibrations set up by the vocal organs, forming distinguishable and intelligible sounds, are called articulate speech. These vibrations, which are roughly represented in Fig. 8, are the most complex in the

FIG. 8.

whole realm of sound—so complex, in fact, as to defy mathematical analysis; but it is certain that their variations in loudness, pitch, and timbre depend upon the facts already outlined. By means of these variations we are not only enabled to understand the words spoken by others, with all their various shades of intonation and corresponding shades of meaning, but we are enabled to distinguish between the voices of the many people with whom we are acquainted.

25. Difficulties of Transmission.—From these facts, it becomes evident that the transmission of articulate speech between two distant points by any means whatsoever is a problem involving difficulties far greater than those of telegraphy, where transmission of single waves or impulses following each other in the proper succession is all that is required. In telephonic transmission, not only must the constantly varying rate and amplitude of vibration be faithfully reproduced at the receiving end of a line, but the fundamental tone and all the overtones must be reproduced, giving each its proper value and without altering the phase relations between them.

HISTORY AND FUNDAMENTAL PRINCIPLES OF TELEPHONY.

EARLY EXPERIMENTS.

26. The successful production of the telegraph by Professor S. F. B. Morse, in 1838, was the forerunner of the telephone, as it formed the first practical application of electricity to the transmission of intelligence. The successful speaking telephone was not, however, produced until 1876, nearly forty years later, although many attempts were made which resulted in total or partial failure, because the electrical principles involved, as well as the laws of acoustics, were evidently not thoroughly understood by the experimenters.

To follow briefly these experiments is not only interesting but instructive, in that it clearly shows many points which must be avoided in the design of successful telephone instruments.

BOURSEUL'S PROPOSED METHOD.

27. In 1854, a Frenchman, Charles Bourseul, proposed a method for the actual transmission of speech between distant points, which, but for one error, would have produced, if followed out, a practical speaking telephone. His words were as follows: "Suppose that a man speaks near a movable disk sufficiently pliable to lose none of the vibrations of the voice, and that this disk alternately makes and breaks the current from a battery; you may have at a distance another disk which will simultaneously execute the same vibrations. * * * It is certain that in a more or less distant future, speech will be transmitted. I have made experiments in this direction; they are delicate, and demand time and patience, but the approximations obtained promise a favorable result."

REIS' EXPERIMENTS.

28. In 1861, Philip Reis, following somewhat closely the ideas set forth by Bourseul, produced a set of instruments that were capable of transmitting musical tones with considerable accuracy, and it is also possible that the actual

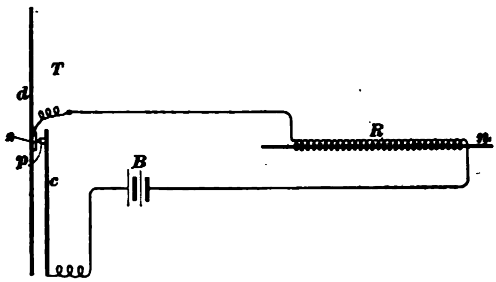

FIG. 9.

transmission of speech was also accomplished. If speech was not transmitted, it was simply because Reis did not adjust his instruments properly. The principles of Reis' apparatus are shown in Fig. 9. The receiver is represented at *R* and the transmitter at *T*. The transmitter consisted of a thin membrane or diaphragm *d* mounted in an opening of a rectangular box, as shown in Fig. 10. A mouthpiece *m* was provided in one side of

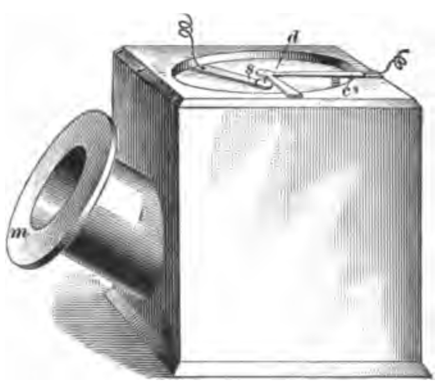

FIG. 10.

the box, into which the sounds to be transmitted were directed. The vibrations set up in the air caused the diaphragm to vibrate to and fro in the manner already described. Carried on the diaphragm *d* was a thin copper strip *s* going to a platinum disk at the center of the diaphragm. Almost touching this disk was a platinum contact point fixed to a stationary piece of copper *c* fastened to the box. Now, as the diaphragm vibrated up and down, the platinum disk alternately made and broke contact with the platinum point.

The receiver *R* consisted of a knitting-needle *n*, on which were wrapped many turns of insulated wire. The needle was mounted in a box of resonant wood, as shown in Fig. 11.

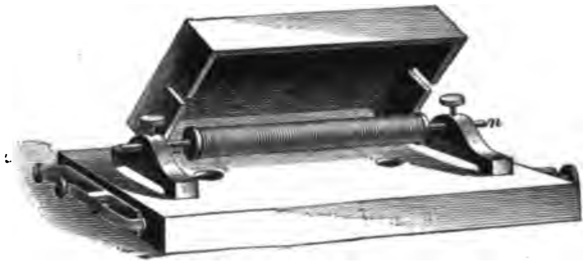

FIG. 11.

29. Action of Reis' Apparatus.—The action of this receiver was based upon a fact pointed out by Page in 1837, that a rod of iron suddenly magnetized or demagnetized would emit certain sounds or clicks due supposedly to a rearrangement of the molecules caused by the changes in magnetism. It is also known that the magnetization of a rod causes it to become slightly longer, due probably to the same molecular rearrangement. The box in which Reis mounted his receiver served as a sounding-board to amplify any sounds produced by changes in magnetism of the needle. These two instruments were connected in one circuit, together with a battery *B*, as shown in Fig. 9. At each vibration of the diaphragm *d*, the circuit through the battery was made and broken, thus allowing impulses of current to flow through the coil surrounding the knitting-needle. This, of course, alternately magnetized and demagnetized the rod, thus producing a sound having exactly the same rate of vibration as the diaphragm.

Reis thus followed the method pointed out by Bourseul, and in doing so made the same error that Bourseul had made. This was in so adjusting his instrument that the vibrations of the diaphragm caused the contact points to alternately make and break the circuit instead of maintaining the contact at all times, and merely causing variations in pressure between them by the vibrations of the diaphragm. As long as the instrument was adjusted to make and break contact, it could transmit the pitch of the fundamental note, but not relative loudness or timbre. This instrument does not transmit variations in loudness, because the electric current always rises to the same maximum value, and again falls to absolute zero as the contact is made and again broken. It does not transmit timbre, because the circuit is made and broken just as many times per second as there are vibrations in the fundamental note, there being no means whatever for transmitting the vibrations of the large number of overtones which must accompany articulate speech. However, his so-called Page receiving instrument, Fig. 11, if connected to a properly adjusted transmitter, can be made to reproduce fairly well not only the pitch of the fundamental, but also the timbre and loudness. With this type of transmitter, a battery in the circuit is necessary.

It hardly seems possible that Reis, in the elaborate series of experiments that he undoubtedly made, could have avoided such an adjustment as would have maintained a constant contact between the platinum points and the copper strip *c* and still have allowed the diaphragm to vibrate, thus causing variations in pressure between the contact points without actually breaking the circuit. The fact remains, however, that Reis' invention was not brought to a practical degree of perfection, and remained in obscurity for a period of fifteen years. In 1876, Professor Alexander Graham Bell and Professor Elisha Gray, both Americans, filed in the United States Patent Office on the same day, and almost at the same hour, their applications for patents on speaking telephones, each of which contains the elements now embodied in our perfected apparatus.

BELL'S EARLY INSTRUMENTS.

30. The first form of instrument constructed by Bell, in 1876, was the so-called harp of steel rods shown in Fig. 12. This instrument consisted of a number of steel rods *H*, varying gradually in length, attached to one end of a permanent magnet $N S$. A single soft-iron core, over which was wound a single coil of insulated wire, was fastened to the

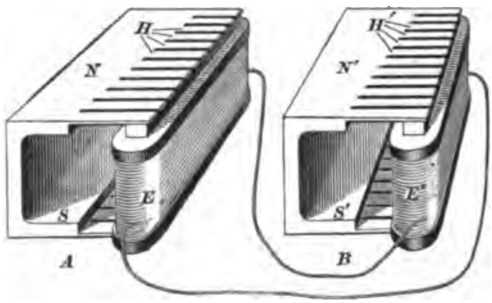

FIG. 12.

other pole of the permanent magnet. The receiving and transmitting instruments are exactly alike, and it should be noticed that no battery is used.

Consider A as the transmitting instrument. When any one of the rods of A is thrown into vibration sympathetically by a simple sound wave in the surrounding air, the distance between the rod and core is varied. The variation in this distance causes a similar variation in the reluctance of the magnetic circuit, which in turn causes the number of lines of force to increase as the distance decreases, and to decrease as the distance increases, thereby generating in the coil of wire E surrounding the core a simple alternating electromotive force, and this electromotive force causes a simple alternating current, having exactly the same frequency as that of the simple sound wave, to flow through the circuit. This current circulating through the coil E' will increase and decrease the magnetism of the core inside it, and cause to vibrate only that rod which, on account of its length and size, has naturally exactly the same pitch as the vibrating rod at A which caused this current. This rod is said to be set into vibration sympathetically with the changes in magnetic strength of the iron core of E'. Not only have the two rods the same pitch, but the amplitude of vibration of the first determines the amplitude of vibration of the second, because the more vigorously the first vibrates, the greater will be the maximum value of the current generated, and therefore the greater will be the variation in the pull between the core and the rod at *B*. Therefore one rod is able to transmit not only pitch, but a variation in loudness. By having a large number of rods—one for each note on the piano, for instance—musical sounds could be fairly well transmitted. Furthermore, if there could be as many rods in each instrument as there are different pitches, within the limits of audibility, then speech could be transmitted, for it is evident that then any number of possible pitches, each with any degree of loudness, could be sympathetically taken up by the rods at *A* and given out by the corresponding rods at *B*, with the same relative loudness. To successfully accomplish this, however, would require an infinite number of rods, which would render the instrument utterly impracticable. It should be understood that no battery is necessary with these permanent-magnet instruments.

31. Two more of Bell's early instruments are shown in Figs. 13 and 14. The transmitter shown in Fig. 13 consisted of a double-pole electromagnet (not a permanent

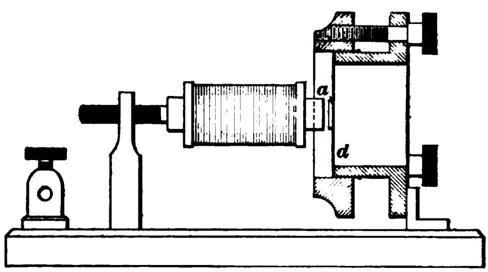

FIG. 13.

magnet) mounted in a horizontal position in front of a vibrating diaphragm *d* of gold-beater's skin, carrying a small soft-iron armature *a* glued at its center. This diaphragm was tightly stretched across a framework having an opening for a mouthpiece, and when set in vibration by the sound waves, caused the armature *a* to alternately move towards and from the poles of the electromagnet. The receiver consisted of an electromagnet *m*, Fig. 14, mounted vertically in a hollow soft-iron cylinder *n*. The top of this cylinder was almost closed by a thin sheet-iron disk, secured only at one side of the cylinder and slightly sprung away from its upper edge, so as to be free to vibrate when acted upon by the electromagnet. The lower end of the cylinder was closed by an iron disk, to which the lower end of the magnet core was attached in such a manner that the magnetic circuit was rendered complete, except for the slight break between the diaphragm and the core. These two instruments were connected in series in the same circuit with a battery, as shown in Fig. 15. A battery is always necessary whenever a simple, non-polarized electromagnet is used

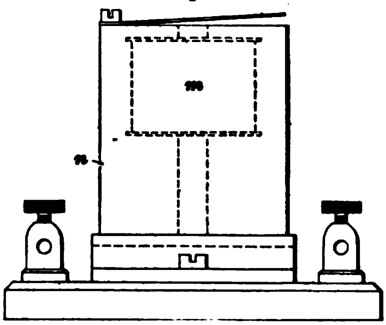

FIG. 14.

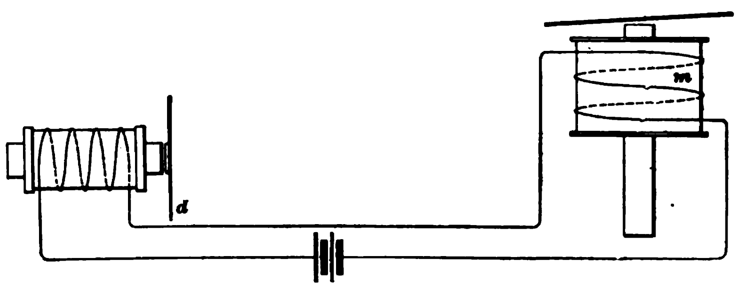

FIG. 15.

in a transmitter. These instruments and this particular arrangement in the circuit formed Bell's famous exhibit at the Centennial in Philadelphia in 1876, which was the introduction of the speaking telephone to the general public. Soon after, this apparatus was somewhat modified, the diaphragm of both receiver and transmitter being made of a thin disk of sheet iron and the core of the electromagnet permanently polarized, it being, in fact, a permanent magnet in itself.

It is interesting to note that Bell first tried a permanent-magnet instrument, the harp of rods, without a battery, then electromagnetic instruments requiring a battery—e. g., his transmitter and tubular receiver exhibited at the Philadelphia Centennial—and, finally, permanent-magnet instruments, but with sheet-iron diaphragms for both the transmitter and the receiver.

THE MAGNETO-TELEPHONE.

32. Bell's apparatus, modified as described in the latter part of the last paragraph, is one of the most remarkable pieces of apparatus ever devised. It comprises the simplest form of electric telephone, and may be used as either a transmitter or a receiver.

33. A **telephone transmitter** is an instrument that takes up the vibrations of the sound to be transmitted and causes corresponding fluctuations of electric current to flow in the circuit in which it is connected.

34. A **telephone receiver** is an instrument that receives fluctuating currents corresponding to sound waves and translates them into distinguishable sounds.

FIG. 16

The action of Bell's instrument will be understood by reference to Fig. 16, in connection with the following description.

35. Action as a Receiver.—A thin diaphragm *P* is mounted close to, but not touching, one pole of the permanent magnet *NS*. A coil of fine wire *C* is wound about one end of the magnet, and the terminals of this coil are connected directly in the circuit in which the instrument is to be used.

It is evident that the diaphragm will normally be strained slightly towards the magnet by the attraction of the latter. If a current is sent through the coil in such a direction that the lines of force set up by it coincide with those of the permanent magnet, the strength of the magnet will be increased and the diaphragm will be pulled still closer to the pole. If, however, a current is sent through the coil in such a direction as to set up lines of force opposing those of the magnet, the strength of the magnet will be diminished and the diaphragm allowed to spring farther away from the pole.

If a current which is undulatory, but always in the same direction, is sent through the coil, the lines of force induced by it in the magnet will increase while the current is increasing and will decrease while it is decreasing. Thus, whether the lines induced by the coil are in the same direction as those of the magnet or not, the varying pull on the diaphragm will cause vibrations in the latter which will be in harmony with the changes in current.

Again, if the current is an alternating one—that is, one which flows first in one direction and then in the other—the lines set up by it in the magnet will change their direction every time the current changes its direction. They will thus, while flowing in one direction, add to the strength of the magnet, and while flowing in the other, diminish it, thus producing a similar variation in attraction between the core and the diaphragm, as in the case of the undulatory current.

36. Action as a Transmitter.—In the preceding article, we have seen that an alternating current sent through the coil would cause the diaphragm to vibrate.

The converse of this statement is true; for if the diaphragm of the instrument is caused to vibrate by some external means, corresponding alternating currents will be caused to flow in the coil—provided, of course, that its circuit is closed and that there is no battery in the circuit. This is true because the movement of the diaphragm towards the pole of the magnet increases the number of lines of force passing through the coil, and as has been pointed out in *Principles of Electricity and Magnetism*, the changing of the number of lines of force through a closed circuit will cause currents to flow in that circuit. Similarly, when the diaphragm moves away from the pole, the number of lines passing through the coil will diminish and thus cause a current to flow in the opposite direction. Thus, for an outward movement of the diaphragm, we will have a current in the coil in one direction, and for an inward movement a current in the other direction.

37. Mutual Action of Two Instruments.—Two instruments like that shown in Fig. 16, if connected in one circuit, as shown in Fig. 17, represent the apparatus and arrangement of Bell's improved telephone.

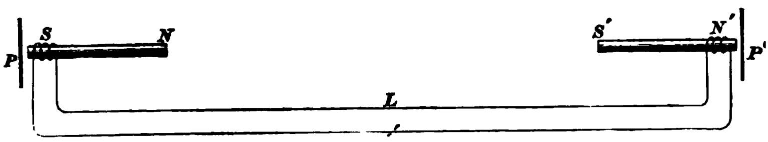

FIG. 17.

When the soft-iron diaphragm P is spoken against, it takes up the vibrations of the sound waves, and thus causes changes in the strength of the magnetic field in which the coil lies. These changes, as shown above, cause currents, first in one direction and then in the other, that is, an alternating current, to flow in the circuit. These currents vary in direction, strength, and frequency of alternation in every way in unison with the movements of the diaphragm, and therefore have all the characteristics corresponding to the relative loudness, pitch, and timbre of the sound that caused the diaphragm to vibrate.

Passing along the line-wire, these feeble currents alternately strengthen and weaken the permanent magnet at the other instrument and cause it to exert a varying pull on the diaphragm, which thus vibrates in unison with the changes in current, and therefore faithfully reproduces the first sound.

The action described as taking place in the instrument *spoken to* is that of a *transmitter*, and that in the instrument which *repeats the sound* is that of a *receiver*.

38. The instrument consisting of a permanent magnet, a coil, and a vibrating iron diaphrägm is called a *magneto-telephone*. Many forms of this instrument have been devised, but all contain the same essential parts, though frequently these parts are duplicated.

39. Sensitiveness.—As a receiver, the magneto-telephone is marvelously efficient and one of the most sensitive instruments known in science. Its sensitiveness depends a great deal upon its construction, adjustment, and the frequency of the current. Houston and Kennelly state that with an ordinary Bell receiver an alternating-current strength of $\frac{44}{1,000,000,000}$ amperes caused a distinctly audible sound. For this determination, an alternating current of 640 periods per second, which was determined to be the best rate for detecting feeble currents, was used.

In 1887, W. H. Preece determined that a Bell receiver would respond to a current of $\frac{6}{10,000,000,000,000}$ amperes, or six ten-thousand-millionths of a milliampere.

Lodge has quite recently stated that the energy required to work his telephone, which is about 30 times as sensitive as an ordinary one, was a millionth of a millionth of a watt for giving an audible signal.

As a transmitter, however, the magneto-telephone has not proved generally successful, as the amount of energy derived from the sound waves is so extremely small that the currents generated by the movements of the diaphragm soon become lost when transmitted over lines of considerable length.

However, the magneto-instrument used as a transmitter generates a current which almost perfectly represents the sound striking its diaphragm, in pitch and timbre, thus insuring remarkable clearness or distinctness, although at the sacrifice of loudness in the reproduced sounds. Low speech can be readily understood by any person not hard of hearing, if it is only distinct or clear. Of course loudness is a very desirable feature, especially where other disturbing sounds not coming from the telephone receiver are present.

THEORY OF MAGNETO-INSTRUMENTS.

40. The permanent-magnet receiver is a great improvement over the electromagnetic instrument. The magnitude of attraction or repulsion between the core and the diaphragm depends not only on the strength of the varying current, but also on the strength of the permanent magnet. The stronger this magnet the better, provided that the diaphragm is far from being magnetically saturated, for then a given change in the current would have less effect on the diaphragm. What is desired is to produce as great a movement of the diaphragm as possible by a given variation in the current. Now, the force of attraction between the diaphragm and the pole varies as the square of the magnetic force between them. If H be the steady magnetic force due to the permanent magnet, and if the fluctuating force varies from $+h$ to $-h$, then at one extreme position, the force between the diaphragm and the magnet is proportional to $(H+h)^2$, and at the other extreme position it is proportional to $(H-h)^2$. The maximum variation in the force is then proportional to the difference between these two values. $(H+h)^2 - (H-h)^2 = 4\,H\,h$. Therefore, the variation in the force is proportional to the quantity $4\,H\,h$, that is, to four times the product of the permanent and variable magnetic forces. From this consideration alone, it would appear that by indefinitely increasing the strength of the permanent magnet, the force of attraction and repulsion, and therefore the amount of motion of the diaphragm and the loudness of the sound, could be indefinitely increased.

But as the diaphragm approaches magnetic saturation, there will be a loss instead of a gain by increasing the strength of the permanent magnet, because when the number of lines of force is very large, causing either the soft-iron core or the diaphragm or both to be magnetically saturated, then a variation of the current in the coil would alter the number of lines of force through the magnetic circuit by an imperceptible amount. Consequently, the force exerted between the diaphragm and the soft-iron core would change by an imperceptible amount. To prevent saturation of the diaphragm is one reason why large, powerful magneto-transmitters require larger and especially thicker iron diaphragms.

If no permanent magnets were used at all, then, even if h, the variable force, was very large, a very inferior instrument would be the result. It would probably be indistinct, due to rattling of the diaphragm, because the constant tension on the diaphragm produced by a permanent magnet would be absent. For a transmitter using powerful magnets, a comparatively large and thick diaphragm, and for receivers a ferrotype or thin iron, have proved to be the best.

In regard to the motion of the diaphragm, the original, and perhaps natural, idea was that it vibrated in nodes and loops only, but by experiment it has been shown that there is a swelling in and out at the center. However, it does not appear conclusive because its vibrations in and out only are visible and measurable, that there may not at the same time be some imperceptible node and loop vibrations. Du Moucel thought that the sound was originally caused solely by the Page effect (see Art. **29**), and that this effect was then strengthened by the diaphragm. This explanation has been shown to be insufficient, although instruments have been made to work, but very feebly, without any diaphragm.

Molecular changes therefore appear to play some part in the action.

In the receiver now used, the shell shields the diaphragm from extraneous sounds, and the very thin air-space between the diaphragm and mouthpiece avoids disagreeable resonance effects. There are no aftertones in a magneto-receiver; that is, the diaphragm does not tend to take up a period of vibration of its own, and so continue to vibrate, depending upon its natural rate of damping to come to rest after its forced vibrations produced by the variable currents in a receiver or by the air waves in the transmitter have stopped. For the magnet itself is a damper, because if the diaphragm did not immediately come to rest, it would be generating by its motion either a current in the coil or eddy currents in the magnet and diaphragm, which currents would be flowing in such a direction as to oppose the motion producing them, and these currents would also require the expenditure of energy to generate them; but there is no external source of energy to keep the diaphragm vibrating, and therefore it must come to rest instantly.

To attain the best results, there is a best strength for the permanent magnet; the soft-iron core should be only long enough to pass through the coil, and the coil should be located on this core where the change in the number of lines of force at right angles to the winding is greatest. Neither the soft-iron core nor diaphragm should be nearly magnetically saturated, and there is a best diameter and thickness of the diaphragm for a given strength of the permanent magnet.

BATTERY TRANSMITTERS.

41. As already stated, the magneto-telephone, while capable of transmitting speech with great distinctness, preserving with great accuracy the quality of the tone, is not well adapted for a commercial transmitter, its action being so feeble as to render transmission over long distances very difficult. To overcome this difficulty, a class of instruments depending on an entirely different mode of operation was devised. These instruments, instead of causing the transmitter to act as a generator of electricity, served to produce variations in the strength of a current already supplied by some other source. The battery transmitter may therefore be said to act as a valve in the circuit, the valve itself requiring but little energy to operate it, but capable of controlling a far greater amount of energy flowing from the battery.

GRAY'S WATER TRANSMITTER.

42. The first instrument of this type was devised by Elisha Gray and formed a part of his early telephone. This is shown in Fig. 18, in which *D* is a vibrating diaphragm, carrying at its center a needle point *p* of platinum, immersed in a fluid of rather low conductivity, such as slightly acidulated water. The other terminal of the transmitter was

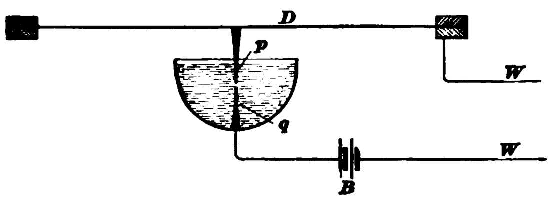

FIG. 18.

formed by a similar needle *q* projecting into the fluid from below. Vibrations of the diaphragm caused the needle *p* to vary the length, and therefore the resistance, of the path frcm one point to the other through the liquid. The variations in resistance thus brought about by the vibrations of the diaphragm caused corresponding variations in the current from the battery *B* connected in the circuit, which variations were then capable of acting on the receiver connected with the wires *W*, *W*, in precisely the same manner as has already been described. The results obtained from the water transmitter were scarcely better than those from the magneto-transmitter, and it had obvious disadvantages due to the necessary presence of a liquid, and therefore never came into commercial use. It was, however, the first transmitter constructed embodying the idea of causing the vibrations of the diaphragm to *vary the strength of the current by changing the resistance of the circuit* in which it was flowing. It was not long before a far better way was found of causing this variation in resistance, and this was by causing the vibration of the diaphragm to produce a *variation in pressure* between two electrodes or terminals in *constant contact*, the variation in pressure causing a corresponding change in the resistance at the contact surfaces, and therefore a change in the total resistance of the circuit.

BERLINER'S TRANSMITTER.

43. A patent, covering broadly this form of transmitter, has been granted to Emile Berliner, who produced the apparatus in 1877, but did not obtain his patent until 1894. Berliner's transmitter is illustrated in principle in Fig. 19, in which *D* is a diaphragm of ordinary tinned iron resting against a ball *E* carried on a thumb-screw. This thumb-screw is mounted in a bracket *C* in such a manner as to afford a means for adjusting the pressure between the diaphragm and the ball. Variations in pressure between the diaphragm and the ball caused corresponding variations in resistance, and thus caused similar fluctuations in the current strength. In Berliner's first transmitter, the diaphragm was about four inches in diameter, of ordinary tinned iron and mounted very roughly over an opening in a wooden box. The back contact consisted simply in a

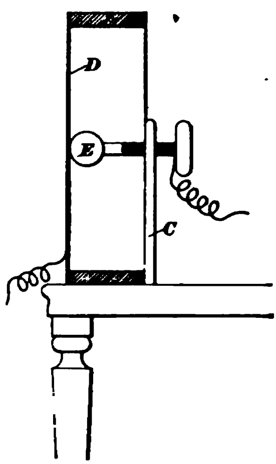

FIG. 19.

blued-iron wood-screw. There has been much discussion as to whether or not this instrument ever actually transmitted speech, but it is certain that it was not a transmitter suitable for practical use.

EDISON'S CARBON TRANSMITTER.

44. Soon after the production of Berliner's instrument, it was found by Edison, as a result of experiments with various semiconductors, that carbon was by far the most suitable material for the electrodes of such a transmitter. One form of Edison's transmitter is shown in Fig. 20; in this *D* is the vibrating diaphragm, against which presses a small button *K* of ivory, having attached to its rear face a thin platinum disk *h*. In the rear of the casing of the instrument is an adjustment screw *E* having an enlarged head *e*, which carries on its front surface another thin disk of platinum *f*. Between these two disks is placed a cylindrical button *g* of compressed lampblack. The two platinum disks form the electrodes of the transmitter, and it is evident that the vibrations of the diaphragm are transmitted to the front platinum disk, thus causing it to exert a varying pressure on the button of lampblack between it and the disk *f*. These variations in pressure cause corresponding variations in resistance, and therefore, according to Ohm's law, transform the steady current which would be flowing when the transmitter is not in motion into an undulating current. Transmitters of this type produce undulating currents and not alternating currents, such as produced by the Bell magneto-instrument when used as a transmitter. An undulating current may be defined as a current whose strength fluctuates, but whatever be the strength of the current, it always flows in the same direction through the circuit.

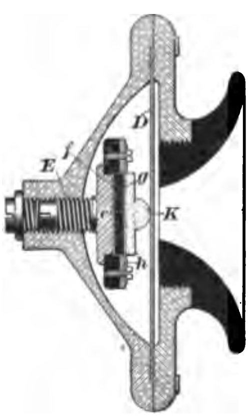

FIG. 20.

HUGHES' DISCOVERIES.

45. Electrodes in Loose Contact.—Up to this time, the best conditions for producing changes in resistance between two electrodes by varying the pressure between them had not been realized. Professor David E. Hughes, in 1878, by a long and interesting series of experiments, proved that the resistance of two conductors in loose contact with each other was far more susceptible to changes in pressure than if they were pressed firmly together. He found that these laws held for any conducting material whatever, and one of his experiments consisted in producing a transmitter made from three wire nails arranged as is shown in Fig. 21. In this the nails *A* and *B* form the terminals of the circuit, which includes a battery and a receiving telephone, the circuit between these two nails being completed by nail *C* laid loosely across the other two. Any vibrations in the air caused corresponding vibrations of the nails, and thus produced variations in resistance at the surfaces where *C* came in contact with *B* and *A*.

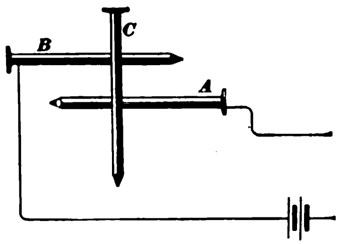

FIG. 21.

46. Hughes' Microphone. — In Fig. 22 is shown another transmitter produced by Hughes, and called by him the microphone, because he considered that it accomplished in acoustics what the microscope did in optics. It consists of two carbon blocks *b*, *b* mounted on a diaphragm *d* of thin, dry wood. Supported in recesses on the upper and lower sides, respectively, of the two blocks *b*, *b* is a small carbon pencil *p*. The two blocks *b*, *b*

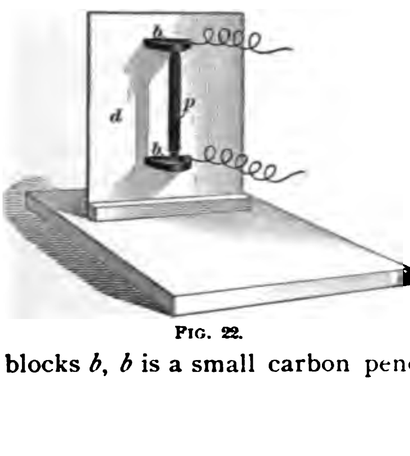

FIG. 22.

formed the terminals of the circuit in the same manner as did the two nails in Fig. 21, the circuit between them being completed by the carbon pencil. Any vibrations of the diaphragm caused by sound waves produced changes in the resistance at the contact surfaces between the terminals of the transmitter, and corresponding changes in the current flowing through the circuit. This instrument proved so marvelously sensitive as to merit the name given it by its inventor. Small sounds, such as a faint scratching on the diaphragm or on the support upon which it rested, so faint as to be entirely inaudible, produced loud noises in the receiver. So delicate was this instrument, however, that it proved unsuitable for ordinary telephone transmission. Noises of moderate loudness produced such an uproar in the receiver as to entirely destroy the original quality of the sound. This is largely due to the fact that a violent vibration between the electrodes causes the circuit to break entirely at times. This defect, however, has been remedied in a number of ways, as will be seen later.

HUNNING'S TRANSMITTER.

47. Granular Carbon Transmitter.—Still another step in the development of the battery transmitter was made by Henry Hunning, in 1881. He introduced the idea of using granulated material, preferably carbon, in a loose state, as the variable resistance medium of transmitters, and all the so-called long-distance instruments are now constructed in this manner. Hunning's original device was very similar to that shown in Fig. 23. Clamped between the wooden block *B* and the mouthpiece *A*, which

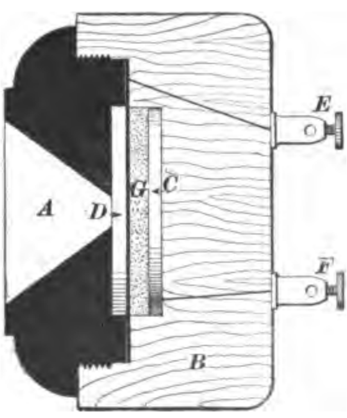

FIG. 23.

may also be of wood or of hard rubber, is a thin diaphragm D of some elastic non-corrosive conducting material. Hunning used a platinum diaphragm, but this, on account of its high cost, has generally been superseded in a large class of instruments by a diaphragm of thin carbon. Within the chamber behind the diaphragm is mounted a block of carbon C, and the space between this and the diaphragm is filled, or partially filled, with granulated carbon, resembling in appearance ordinary gunpowder. Finely pulverized carbon was at first used, but this packed so easily that it was soon superseded by the granulated carbon. The two binding-posts E and F are connected, respectively, with the diaphragm and with the carbon block, the circuit between them being completed by the carbon granules.

In this we have a large number of loose contacts between the granules and the diaphragm, between the granules and the back block, and also between the granules themselves. The sound waves entering in the mouthpiece produce vibrations of the diaphragm, which vary the pressure at the multitude of loose contacts, and thus vary the resistance of the circuit.

THEORY OF MICROPHONE TRANSMITTER.

48. The action of the microphone transmitter has been, and still is, the subject of much discussion by scientists. Four different explanations have been put forward as to why a change in the pressure between two electrodes of carbon or of other material produces the wonderfully sensitive effects on the resistance through the point of contact.

49. Changes in Actual Resistance of Carbon.—The first of these theories is based upon the supposition that carbon in itself has the property of changing its resistance when subjected to pressure, the resistance becoming lower as the pressure is increased. It was upon this supposition that the early transmitters of Edison, using carbon as the variable resistance medium, were constructed. It has been recently proven, however, that the resistance through a rod of carbon is not changed perceptibly by increasing the pressure up to the crushing point of the carbon.

50. Occluded-Air Theory.—The second theory is one set forth and apparently still adhered to by Mr. Berliner. It is that the surfaces of the electrodes are held slightly apart by a thin film of air which collects over the entire surface of the electrodes and therefore prevents actual contact between them.

In order to accept this theory, we must believe that the air that is occluded on the surface of the electrodes possesses different characteristics from the air with which we are generally acquainted. A layer of air in its ordinary state, as thin as physical means could produce, would possess an almost infinite resistance, and as the resistance of a microphone contact is but a few ohms at most, it follows that this ground is not tenable. If, however, the air is in some different state, it may be that it possesses conducting properties to some degree. Under this view, Berliner's theory does not seem altogether improbable, and the possibility that air might, under certain conditions, possess these properties is not denied by prominent physicists. Were it the case, however, that the electrodes were thus held apart by a film of air, the conditions would be similar to that of two conducting bodies immersed in a conducting fluid. It is found by experiment that the resistance between two such bodies is unaffected by the distance between the bodies, provided they are of small size in comparison to the cross-section of the liquid. If, therefore, a curve be plotted as shown in Fig. 24, representing the distance between the bodies on the horizontal line *X* and the corresponding resistances between them on the vertical line *Y*, it will assume the form shown at *A*, the resistance gradually increasing as the two bodies are separated, but soon becoming a constant, regardless of the distance between them. This latter condition is shown by the flat portion of the curve. If the conducting bodies were flat plates and the distance between them very slight as compared with their diameters, then the curve might assume the form of a straight line, as shown at *B* in Fig. 24. In this case, the resistance would vary directly as the distance between the plates increased.

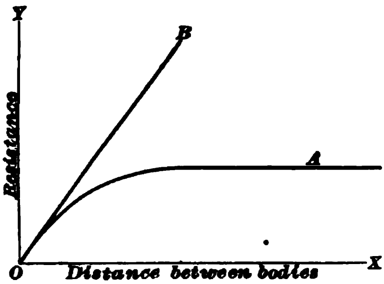

FIG. 24.

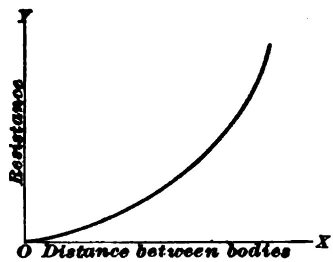

FIG. 25.

An experimentally determined view of the actual behavior of the resistance of the microphone contact shows that the curve is always of the general form shown in Fig. 25. This curve shows the relation between the increase in the distance through which the electrodes move and the corresponding increase in the resistance. It is seen that this curve is of the opposite nature from that which we would expect were Mr. Berliner's theory of occluded air true. It therefore seems probable that this is not the correct theory of the microphone.

51. Heating Effect at Contact.—The third theory is that the heating due to the passage of a current through the point of contact in some way aids microphonic action. It has been shown, by examination of the microphone contact under a microscope, that small arcs were present at the point of contact. It is not clear, however, how these arcs or how the heating effect without the arcs would prove otherwise than detrimental to good transmission.

Some hold that an increase in current, due to a decrease in resistance brought about by an increase in pressure, would cause the particles at the point of contact to become hot, and thus further reduce the resistance. It is true that carbon possesses the peculiar property of lowering its resistance when heated, and it is also undoubtedly true that such an action would take place were the electrodes allowed to remain in one position long enough. It is well established, however, that the rise in temperature following an increase of current is a comparatively slow process, and it is therefore not probable that the decrease in resistance due to the increase in temperature would take place in time for it to be of any particular advantage. On the other hand, it would seem that if this action takes place to any appreciable extent, it would prove detrimental to transmission, because the changes in resistance due to the changes in temperature would lag to an appreciable extent behind the changes in pressure. This would of course tend to destroy the form of the wave and therefore produce changes in the timbre or quality of the voice at the receiving station.

52. Theory of Surface Contact.—The fourth theory is that the changes in resistance brought about by changes in pressure between the microphone contacts are due to changes in the actual area of the contact. The fact that such changes in the area of the surface contact do take place may be well illustrated by pressing a white billiard-ball or similar body lightly against a marble slab previously given a thin coating of graphite. Upon removing the ball, the area of contact will be represented by a small-sized dot of graphite upon it. If now the ball be dropped from a considerable height upon the slab and caught in the hand as it bounds upwards, it will be found that the spot of graphite resulting from the contact will cover quite a large area, thus showing that under the increase of pressure, the surface of the ball was flattened and the surface of the marble slab indented to such an extent as to bring a considerable area of the surfaces of the two into contact. It is clear that if the two bodies were of conducting material, the resistance at the point of contact would vary in proportion to the area of contact.

That such an action as this actually takes place in a microphone contact can not for a moment be doubted, for it is well known that carbon and other materials suitable for such contacts possess a rather high degree of elasticity, and it is certain that they are subjected by the vibrations of the diaphragm to a varying pressure. The form of the curve in Fig. 25 corresponds exactly to what would be expected from theoretical conditions alone, were all the variation in resistance due to increasing pressure brought about by the increase in surface contact. The matter has been carefully studied, and in the case of steel bicycle balls immersed in oil to prevent the occlusion of air on their surface, curves corresponding to that of Fig. 25 have been found to correctly represent the changes in resistance due to varying pressure.

53. The opinion is now held by many leading telephonists that the action of the microphone is due almost entirely to changes in surface contact, and that while some of the actions set forth in the other theories may be present to some extent, they do not in any perceptible manner modify the general result. In the case of rough electrodes, the action might be considered to be brought about by changes in the number of points of contact, but this would clearly be only another way of affecting the area of contact.

This theory is a perfectly satisfactory one, in that it is in accordance with all the experimentally determined facts concerning the action of the microphone. Apparently the chief reason for searching for more complex theories has been that our minds are loth to attribute such marvelously delicate results to such a very simple cause.

54. It has been shown by Professor Fessenden that the oxide formed by a substance to be used for a contact in a microphone transmitter must be a gas or else a conductor, if satisfactory and coherent results are to be obtained in use. This limits us to the use of the following materials: Carbon, osmium, lead, lead sulphide, manganese, and possibly impure sulphur. If, however, the materials be kept in an enclosure, then some gas, such as chlorine, may be used instead of air, and all substances forming gaseous chlorides may be used. No substance is equal to carbon, mainly because carbon is so much more elastic that the small prominences which make the contact can stand so much distortion before breaking.

If a metal is desirable as one electrode, platinum or gold is by far the best, because neither corrodes under ordinary conditions.

55. Peculiar Adaptability of Carbon.—The fact that carbon possesses the property of lowering its resistance when heated, while it probably does not, as already pointed out, affect the actual microphonic action, is of great advantage in reducing the resistance of the transmitter as a whole while it is heated by the passage of currents. As the transmitter becomes hot, due to the flow of a heavy current through it, its resistance is lowered instead of raised, as would be the case were almost any metal used; and this is advantageous, in that it reduces the total resistance of the local circuit and thereby allows a greater current to flow.

THE INDUCTION-COIL IN TELEPHONY.

56. Review of Microphonic Action.—In order to more readily comprehend another development that was

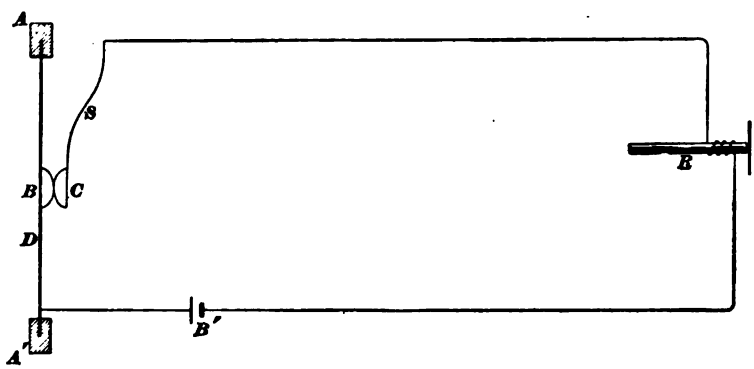

FIG. 26.

made at an early date, the action of a variable resistance transmitter when placed in circuit with a receiver will be reviewed, reference being made to Fig. 26. In this figure, a carbon button B is mounted upon a flexible diaphragm D supported at its edges in a stationary ring A A', as shown. Against the button B rests a similar button C, also of carbon, carried on the spring S. The diaphragm and spring form the terminals of wires leading to the receiver R, one of which wires includes a battery B'. While the instrument is at rest, a steady current flows through the circuit, of which the two carbon buttons and the coil of the receiver form a part. If the diaphragm is caused to vibrate in the slightest degree, a variation in pressure at the point of contact between the buttons will take place, which will cause a corresponding variation in the area and therefore in the resistance of the contact. This in turn produces fluctuations in the strength of the current, which travel along the line-wire and act on the diaphragm of the receiver. Sounds, such as spoken words, uttered against the diaphragm D will cause it to vary the pressure between the buttons in such a manner as to produce fluctuations in the current flowing in the circuit from the battery B', which fluctuations will be in exact unison with the sound waves, and will therefore cause the diaphragm of the receiver to vibrate in unison with that of the transmitter. The battery transmitter therefore serves, not as a generator of electricity, as in the case of the magneto-transmitter, but as a valve to control the flow of current from another source, that is, from the battery B'.

57. Transmitter in Line Circuit.—Where a transmitter is included directly in the circuit with a line-wire, as shown in Fig. 26, it is obvious that if the line is long and the resistance of its circuit comparatively high, a small fluctuation in the resistance of the transmitter will produce but a slight change in the total resistance of the circuit, and therefore will affect the flow of current in the circuit to but a slight degree. It is exceedingly important that the variable resistance in all microphone transmitters should be large compared to the total resistance of the same circuit, so that the fluctuations in the current shall be large.

To illustrate, suppose the resistance of the entire circuit to be 1,000 ohms, and that the transmitter is capable of producing a change in this resistance of 1 ohm; the transmitter will therefore be capable of producing a change in the total resistance of the circuit of one one-thousandth of its original value, and as a result the current flowing in the circuit will be changed by an amount equal to one one-thousandth of its normal value.

58. Transmitter in Local Circuit.—It is evident that a high resistance in a circuit where this arrangement is used is detrimental to powerful transmission in two ways: in the first place, the high resistance will render the normal current flowing from a given source comparatively small, and in the second place, the small ratio that the changes in resistance brought about by the transmitter bears to the total resistance of the circuit will render the fluctuations in this already small current very slight. In order to remedy this defect, it has become common practice to place the transmitter and battery in a local circuit containing also the primary winding of a small induction-coil. This is necessary in order that the resistance external to the variable contact resistance of the microphone should be small. This applies to the internal resistance of the battery, to all connecting wires, joints, and the primary winding of the induction-coil. The secondary winding of this coil is placed directly in the circuit of the line-wire with the receiving instrument, the arrangement of circuits being as shown in Fig. 27, in which T is the transmitter, B the battery, P the primary winding of the induction-coil, S the secondary winding, and R the receiving instrument at the distant station. The resistance of the local circuit in this case is usually made very low, less than 7 ohms, but we will say, for convenience, that it is 10 ohms. If the same transmitter as in the preceding case is used in this circuit, it will still be able to produce a change in the resistance of 1 ohm, and this change will bring about a change in the total resistance of the circuit of one-tenth of its normal value;

from which it follows that the total change in the current value in the transmitter circuit will be one-tenth of its normal amount, or 100 times as great as in the case where the transmitter was included directly in the line-wire. Not only will the change in current bear a far greater ratio to the normal current flowing, but the normal current itself will with the same battery power be 100 times as large, because the resistance of the circuit is but one one-hundredth of the value assumed in the previous case.

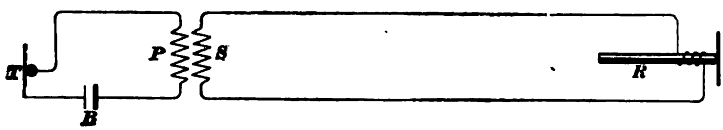

FIG. 27.

It may at first sight appear that the larger the primary current, the better would be the results at the receiver. But it is necessary to remember that owing to the heating effect of the current at the contact points of the microphone, there is a best normal current, probably different for each kind of transmitter, above which it is not safe to increase the current. Thus, it is quite easy, by using too strong a current in the transmitter circuit, to so heat up the contact that its speaking qualities are impaired, if not even destroyed altogether.

59. Action Between Primary and Secondary Coils.—The primary winding of telephone induction-coils is usually composed of a small number of turns of comparatively coarse wire wrapped about a bundle of soft iron wires forming a core. The secondary winding is composed of a large number of turns of very fine wire, and is usually wrapped outside of the primary winding, therefore surrounding it and the core also. Whatever lines of force are set up in the core of the coil by the current flowing in the primary winding will pass also through the convolutions of the secondary winding. The fluctuations in the current in the local circuit of Fig. 27 will cause corresponding fluctuations in the number of lines of force set up by the current in the core of the induction-coil. As these lines also pass through the secondary winding of the coil, it follows that, by the laws of electromagnetic induction, currents will be induced in this secondary winding which will correspond to the changes in the number of lines of force passing through the coils, and therefore to the changes in current strength in the primary. The current in the primary or local circuit is undulating, but not alternating; it never changes its direction. The current in the secondary, however, is alternating in character, flowing first in one direction and then in the other. This fact is usually somewhat puzzling to the student, but its explanation is very simple. When the current in the primary winding increases, due to a decrease in the resistance of the transmitter, the number of lines of force through the core of the induction-coil increases. When the current in the primary decreases, the number of lines of force in the core also decreases.

60. It has been shown in *Principles of Electricity and Magnetism* that the direction of an induced current in a coil depends on whether the lines of force through that coil are increasing or decreasing in number, provided of course that the lines continue in the same direction. In the induction-coil, as shown in Fig. 27, the lines of force remain in the same direction, because the current producing them does not change its direction; but they are alternately increasing and decreasing in number, and therefore the induced current in the secondary must flow in one direction as long as the lines of force are increasing, and then in the other as long as they are decreasing in number.

INSTRUMENTS DEPENDING ON CAPACITY.

61. Condenser Instruments.—There is one other type of instrument, which may be used both as a receiver and as a transmitter, which should be mentioned. It is well known that the electrostatic capacity of a simple plate condenser may be made to vary by varying the distance between the plates. Consequently, if a plate condenser be connected in series with a battery and the distance between the plates be made to vary in unison with the sound vibrations, by fixing one plate and talking against the other, its electrostatic capacity will vary, and consequently the charge will vary, causing a current varying in unison with the sound waves to flow in and out of the condenser. Evidently, if the variations in the charge are large enough and a proper receiver be connected in the same circuit, it will give out the original sounds.

A condenser instrument may serve as a transmitter or receiver. Dolbear invented a condenser receiver consisting of two thin metal disks set very close together, but not touching, of course. If these two plates are connected to an ordinary microphone transmitter, the charges upon the condenser plates will vary, since the potential at the plates will vary as the resistance in the microphone varies. This variation in the charges will cause a variation in the force of attraction between the plates, because they have upon them two variable charges of opposite polarity, and therefore the plates will vibrate in unison with the original sound waves. This receiver has not proved successful, however, because it requires a very powerful microphone transmitter and induction-coil, and, furthermore, it is necessary to cut out the high resistance of the secondary coil at the receiving end in order to have the sounds reproduced with sufficient intensity.

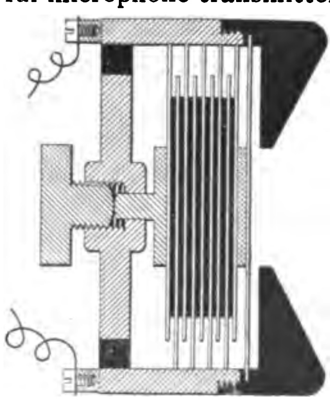

FIG. 28.

In 1877, Edison developed a condenser transmitter which would work, but it required a very powerful electromotive force and consequently a large number of cells to operate it successfully. One form made by Edison was composed of very thin plates separated by paraffin paper, having a mica diaphragm with a cork button between it and the condenser, as shown in Fig. 28. When the diaphragm is set in vibration, the plates are pressed together more or less; thus the distance between them varies, and this changes their electrostatic capacity.

THREE CLASSES OF TRANSMITTERS.

62. There are, as we have seen, three kinds of variations that may be used to produce an undulating or an alternating current for the transmission of speech:

1. Variation of the magnetic reluctance in a magnetic circuit, producing an alternating or variable electromotive force in a circuit, as in a permanent magneto-transmitter.

2. Variation of the resistance in an electric circuit, as in all microphones.

3. Variation of the capacity in an electric circuit, as in the condenser transmitter.

The second method has given by far the best results.

ELECTRICAL CONDITIONS AFFECTING TELEPHONIC TRANSMISSION.

63. Difficulties Preventing Perfect Transmission.—The laws governing the production of articulate speech or of other sounds have been discussed, as have also the various means by which the sound waves may set up corresponding electrical waves in a line, and by which these electrical waves may at the distant end of the line be converted into sound waves resembling as closely as possible the original waves. Perfect telephonic transmission would involve the accurate reproduction at the receiving end of the line of the sound waves at the transmitting end. This would mean that the amplitude, form, and frequency of the reproduced waves should be identical with those of the original waves. The reproduction of the sound waves without ioss in amplitude would clearly involve the transmission of electrical energy with no loss in the line or other parts of the circuit, i. e., with an efficiency of 100 per cent. This is clearly an impossibility. The exact reproduction of the form of the wave would involve the transmission, not only of the wave corresponding to the fundamental tone, but of those of higher frequencies corresponding to the overtones, with no loss, or with the same relative loss in all, and also the maintaining of all the simple waves that make up the complex wave in the same phase relation as in the original wave. This is also an impossibility, because there are certain electrical properties possessed to a greater or less extent by every circuit, which properties tend to alter the form of the complex wave either by reducing the relative amplitude of the waves corresponding to the higher overtones or by displacing in phase the waves corresponding to the overtones with respect to each other or with respect to that of the fundamental tone. These various properties and the effects they produce upon the form or amplitude of the waves may be understood only after some knowledge is obtained of the theory of alternating currents.

ALTERNATING CURRENTS.

64. Alternating-Current Waves. — It has been shown that telephonic transmission is effected by means of alternating or undulating currents of electricity flowing in a circuit containing the receiving and transmitting instruments. It has further been shown that while the wave form of this current is exceedingly complex, it may be considered as being made up of a large number of simple waves, each following in its rise and fall the law of sines. Alternating currents may be generated in many ways, the most common in telephony being those set up by the battery transmitter and induction-coil in the ordinary telephone set, or by the magneto-generator used in generating current for calling purposes.

DIAGRAMMATIC REPRESENTATION OF ELECTRICAL WAVES.

65. Analysis of Curves.—The successive values of the current or of the electromotive force may be represented by means of curves in the same manner as in representing the form of sound waves in the first portion of this Paper. Referring again to Fig. 3, the horizontal line *A B* may be considered to represent time, while the vertical lines *c*, *d*, *e*, and *f* may be considered to represent the instantaneous values of the current or electromotive force at corresponding particular moments. This may perhaps be made clearer by a reference to Fig. 5, where the curve *A B C D E* will be first assumed to represent the values through which the current passes in the course of a complete cycle. The distance *A E* along the horizontal line will then represent the time taken for the current to pass through a complete cycle, and the distance *A f* will represent the time in which the current has risen from zero to a value represented by the line *e f*. *A b* will represent the time taken for the current to pass through a quarter cycle, and the line *B b* will represent the maximum positive value of the current. During the time represented by the distance between *b* and *C*, the current decreases, its value at any time being represented by the perpendicular distance or ordinate between the horizontal line *A E* and the curve. At the point *C*, which corresponds to the end of the first half cycle, the current passes through zero and begins to increase in a negative direction. The distance *A d* represents the time of three-quarters of a cycle, at which time the current has reached its maximum negative value, after passing through which it gradually decreases to zero at the point *E*, which marks the end of the first complete cycle.

66. If the current is generated by a diaphragm vibrating with a simple harmonic motion in the field of an electromagnet, its curve will also be a representation of a simple harmonic motion, and may be considered as being generated by the revolution of the line *O p'*, in Fig. 5, around the point *O*. The distances measured along the horizontal line from the point A may therefore, as in the case of simple harmonic motion, represent the portion of the cycle in degrees through which the wave has passed at any instant. Thus, the distance $A f$ would represent the angular distance through which the line $O p'$ revolved in passing from the position $O A'$ to the position $O p'$, which, as may be seen by mere inspection, is approximately 45°. The distance $A b$ corresponds to the rotation of the line $O p'$ through an angle of 90°, at which time the value of the current is a maximum. In like manner, $A C$ may represent a rotation of 180°, $A D$ 270°, and $A E$ 360°, or a complete cycle. The curve shown in Fig. 3 or 5 may, instead of representing current, represent the successive values of the electromotive force producing the current, the value of the electromotive force at any time being represented by the ordinate of the corresponding point on the curve in exactly the same manner as when the curve was considered as representing the successive values of the current.

67. The length of the line $O p'$ in Fig. 5 is the same in all cases as the lines $B b$ and $D d$, representing, respectively, the maximum and minimum values of the current or electromotive force. It is therefore often convenient, in reasoning or calculating about alternating-current phenomena, to represent the maximum value of the current or electromotive force by such a line as $O p'$, and the phase of the current or electromotive force at any instant by the angle that the line makes with some line of reference, such as the horizontal line $O A'$ in Fig. 5. Thus, the left-hand portion of the figure included within the circle may be used to convey the same meaning as the right-hand portion of the same figure, including the sine curve $ABCDE$. The maximum value of the current is represented by the radius of the circle, and the instantaneous value at any time or at any portion of the cycle may be found by dropping an ordinate from the point p' on the circumference to the horizontal diameter.

68. Complex Alternating-Current Wave.—Fig. 6, which was used to illustrate the production of a complex sound wave A by combining two simple sound waves B and C, may be also used to represent the formation of a complex current wave from two simple sine waves. The maximum values of the currents represented by curves B and C will be represented by the radii of the large and small circles, respectively. The curve A, being a complex instead of a simple harmonic wave, can not be represented by a radius revolving around the center of a circle, as in the cases already described.

69. Effects of Resistance.—Resistance, as has already been pointed out, is that property of a circuit which tends to obstruct the passage of a current. The effect of resistance upon direct or continuous currents has already been described in the Paper on *Principles of Electricity and Magnetism*, the relation between the values of the current, electromotive force, and resistance being defined by Ohm's law, which may be stated as follows: The current in amperes is equal to the electromotive force expressed in volts divided by the resistance of the circuit expressed in ohms. The effect of resistance, when not modified by any other properties of the circuit, such, for instance, as self-induction or capacity, is the same for alternating currents as for direct currents. It causes neither a lag nor a lead in the current wave, nor does it alter the form of the wave, its only effect being to diminish its amplitude. This diminution in amplitude is, under these circumstances, in exact accordance with Ohm's law, the effective or the maximum values of the current for any cycle varying directly with the effective or maximum electromotive force.

SELF-INDUCTION.

70. Electromagnetic Induction. — Self-induction has already been briefly described in Art. **2453** of the Paper on *Principles of Electricity and Magnetism*, but as its influence is most important in telephony and in alternating-current work in general, it will here be described at greater length. Whenever there is such a relative movement between a conductor and the lines of force of a field as to cause the lines of force to cut the conductor, an electromotive force will be set up in the conductor, which tends to cause a current to flow. The direction of the electromotive force will depend upon the direction of the lines of force and upon the direction of the cutting, and its value will depend upon the rate of the cutting. The field of force may be set up either by a magnet or by a conductor carrying a current. This phenomenon is termed electromagnetic induction, and self-induction is one of the phenomena directly attributable to it.

71. Mutual Action Between Turns of a Coil.—In the Paper on *Principles of Electricity and Magnetism*, it is shown that every conductor carrying a current is surrounded by a magnetic field or magnetic whirl. It is evident that in a coil of wire carrying a current, each turn is surrounded by such a field or whirl, and that if the various convolutions are close together, each will lie more or less within the field of the others. Each turn will therefore have an inductive action on the other turns, because when the strength of the current is varying, the lines of force in the field surrounding each turn will, so to speak, contract or expand, thus cutting the wires in the adjacent turns and setting up electromotive forces in them. In two wires lying side by side, an increase in the current in one of them will induce an electromotive force in the other, tending to cause a current to flow in the opposite direction. On the other hand, a decrease in the current flowing in one of them will induce an electromotive force in the other, tending to cause a current to flow in the same direction. The convolutions or turns of a coil form practically parallel wires; and in order to show the effects of self-induction, we will consider the action of one particular turn upon the neighboring turns. When the current flowing in this particular turn suddenly increases, the lines of force set up around the wire of this turn will expand, and in so doing will cut the wires of all the neighboring turns. This will induce an electromotive force in the neighboring turns, which will tend to cause a current to flow in the opposite direction. On the other hand, when the current flowing in this particular turn diminishes, the lines of force will contract, and in so doing induce electromotive forces in each of the other turns, which will tend to produce currents in them in the same direction. Each turn of wire in the coil also acts upon all the others in the same manner as the particular turn that we have considered, thereby greatly magnifying the result. This phenomenon, that is, the action of one part of a circuit upon the other parts, is termed self-induction; and as an increase in the current flowing in one direction through a circuit always tends to induce a current in the opposite direction, while a decrease in the current tends to induce a current in the same direction, self-induction may be said to be that property of a circuit which tends to prevent any change in the strength of a current flowing in it. Self-induction has therefore been defined as the "inherent quality of electric currents which tends to impede the introduction, variation, or extinction of an electric current passing through an electric circuit." The circuit acts as if it possessed magnetic inertia, which resists any change, and especially a sudden change, in the strength of the current flowing.

72. Coefficient of Self-Induction.—The total amount of cutting or interlocking of the lines of force and the turns of a coil, which is set up by a current of 1 ampere flowing through the coil, is called the coefficient of self-induction. This coefficient is usually represented by L. If we represent the total number of lines threading through the coil by N and the number of turns by T, then the total cutting or interlocking when N lines are removed will be $T\,N$, since each line cuts through each of the T turns. Evidently, therefore, for 1 ampere of current $L = T\,N$, and for a current of C amperes, N will be C times larger, since the total induction or number of lines of force surrounding a conductor increases directly in proportion to the current. We have, then,

$$C\,L = T\,N, \text{ or } L = \frac{T\,N}{C}. \qquad \textbf{(1.)}$$

The practical unit of self-induction is the henry; it corresponds to a cutting of 100,000,000 lines of force, when the current turned on or off is 1 ampere; hence,

$$L \text{ in henrys} = \frac{TN}{10^8 C}. \qquad (2.)$$

It will be evident from the above formula that the coefficient of self-induction L may be increased by increasing T, the number of turns, or by increasing N, the total number of lines of force set up through the coil by a given current. The number of turns may be readily increased by winding more wire on a coil, and in order to do this where a limited amount of space is available, it is frequently necessary to wind with a smaller wire. The number of lines of force set up through a coil depends, not only upon the strength of the current, but also upon the character of the magnetic substance in and around the coil. A coil having no iron in its core will have a very much lower coefficient of self-induction than a coil having a core of iron, for the reason that the number of lines of force set up by a given magnetizing force is much greater in iron than in air. We may say, therefore, that a large amount of iron in the core of a coil serves to greatly increase the coefficient of self-induction, and where the return path for the lines of force is also made of iron, as in the case of certain apparatus to be described, the coefficient of self-induction is still further increased, because the entire magnetic circuit is made of iron.

73. Electromotive Force of Self-Induction.—The electromotive force brought into existence by self-induction is called the electromotive force of self-induction, or the pressure of self-induction, in order to distinguish it from the impressed electromotive force or pressure which, as its name indicates, is that impressed upon the circuit by the generator that is causing the current to flow. The active pressure is the resultant of the pressure of self-induction and the impressed pressure.

74. Effects of Self-Induction.—It is evident, since self-induction tends to oppose any change being made in a current flowing in a circuit, that the effect will be to make any change in current strength occur slightly later than it would otherwise do. In a circuit containing only resistance, without self-induction or capacity, an alternating current will be in exact phase with the electromotive force impressed upon the circuit; that is, the maximum value of the current will occur at the same time as the maximum value of the electromotive force, and the corresponding zero and intermediate values of current and electromotive force will also occur at the same times. When self-induction is introduced into the circuit, however, it causes the changes in current to occur somewhat later than the changes in the electromotive force, or, as it is customary to express it, to lag in phase behind the electromotive force.

75. Phase Relations.—The electromotive force of self-induction is proportional at all times to the rate of change of the current flowing in the circuit, and not proportional to the current itself. Therefore the electromotive force of self-induction is a maximum when the current is passing through zero, because at that time the current is changing faster than at any other time. Likewise the electromotive force of self-induction is zero when the current is a maximum; for when the current is a maximum, the rate of change of the current is zero. These facts may be more readily grasped by again referring to Fig. 5. If the curve is taken as representing the instantaneous values of the current, it will be seen that at the zero-points *A*, *C*, and *E*, the current is changing most rapidly, for the curve is steepest at these points, and at these points the electromotive force of self-induction will be greatest. At the maximum points *B* and *D*, the rate of change of current is zero, and therefore the electromotive force of self-induction will be zero.

In Fig. 29 the curve *A B C D E* represents the same curve as that shown in Fig. 5, and in this case it is taken to represent the successive values of the active electromotive force, that is, of the electromotive force that is actually driving the current through the circuit, and which is therefore in phase with the current. The curve $A' B' C' D' E' F'$ represents the electromotive force of self-induction, it being

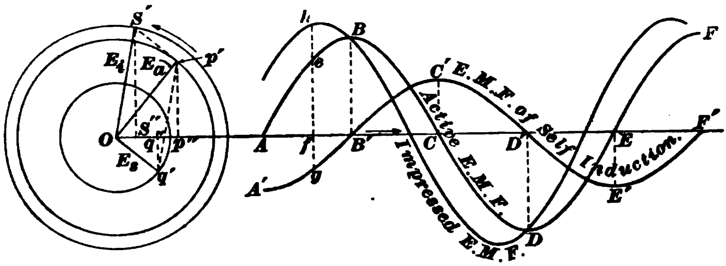

FIG. 29.

so drawn that its maximum values A', C', and E' occur at the same time as the zero values A, C, and E of the active electromotive force. In like manner, the zero-points B', D', and F' occur at the same time as the maximum values B, D, and F of the active electromotive force. A little consideration shows that the electromotive force of self-induction lags behind the active electromotive force by an amount equal to the distance $A\,B'$, or, if expressed in angular measure, by 90°, or a quarter of a cycle. It is always true that the electromotive force of self-induction lags 90° behind the active electromotive force, and therefore 90° behind the active current, which is always in phase with the active electromotive force.

76. Construction of Impressed E. M. F. Curve.—The curve $A\,B\,C\,D\,E$ in Fig. 29 may, as we have already seen, be considered as generated by the revolution of the line $O\,p'$ about the point O. The length of the line $O\,p'$ is made equal to the maximum value of the active electromotive force, and this line is, for the purpose of clearness, designated E_a. The line $O\,q'$ represents the E. M. F. of self-induction, and is therefore termed E_s. Its length is made equal to the maximum value of the electromotive force of self-induction, and as this has been shown to lag in phase behind the active electromotive force by an amount equal to 90°, the line E_s is drawn at right angles to the line E_a and behind it. If the lines E_s and E_a are revolved around O, keeping them at all times the same number of degrees apart, then the line E_s would generate the curve $A' B' C' D' E' F'$, representing the electromotive force of self-induction, while the line E_a was generating the curve $A B C D E F$, representing the active electromotive force. The curve of the impressed electromotive force may be found by taking the algebraic differences of the instantaneous values of the active electromotive force and of the electromotive force of self-induction. Thus, the point h on the curve of the impressed electromotive force may be found by making the length of the ordinate $f h$ equal to the sum of the ordinates $f e$ and $f g$, the sum being taken because the ordinate $f e$ is positive, while the ordinate $f g$ is negative; and to subtract the latter from the former, we have only to change its sign and add, according to the well-known rule of subtraction in algebra. That is, $f h = f e - (-f g) = f e + f g$.

77. Angle of Lag.—The curve representing the impressed electromotive force may be worked out, point by point, by thus taking the algebraic differences between the ordinates of the curve of active electromotive force and that of the electromotive force of self-induction. A better way, however, is by completing the parallelogram of the lines E_a and E_s, as shown at the left hand of Fig. 29. Remembering that the active electromotive force is the resultant of the impressed electromotive force and the electromotive force of self-induction, we have only to draw the line E_i, which represents the impressed electromotive force, making it parallel and equal to the line $p' q'$, so that the line E_a represents the resultant in the ordinary parallelogram of forces, of which E_i and E_s are the sides. The line E_i will then represent by its length the maximum value of the impressed electromotive force, and by its angular position, the phase relation with respect to the active electromotive force and the electromotive force of self-induction. This line, if revolved around the point O with the lines E_a and E_s, would generate the curve representing the impressed electromotive force, as shown; and the complete parallelogram shows the relative values of the impressed, the active, and the self-induced electromotive forces, and the differences in phase between them. The actual current flowing in the line will be in phase with the active electromotive force E_a, and the angle between the line E_t and the line E_a will therefore represent the lag in phase of the current behind the impressed electromotive force. This angle is termed the angle of lag.

ELECTROSTATIC CAPACITY.

78. Condensers.—It has been stated in the Paper on *Principles of Electricity and Magnetism* that all bodies have to a greater or less extent the power of accumulating on their surfaces charges of electricity, and that two such charges mutually attract or repel each other according to whether they are of the same or of opposite sign. It was further stated that the amount of charge which a given conductor would take would be greatly increased by the proximity of another conductor to it. Two conducting bodies placed close together or insulated from each other form what is called a condenser, of which the Leyden jar is probably the best known example. Condensers for commercial work, however, are usually made of a large number of sheets of tin-foil, laid one upon the other, each sheet being insulated from those adjacent to it by sheets of paper impregnated with insulating compound. The alternate layers of tin-foil are connected together at one side and to a point forming one terminal of the condenser, while the remaining plates are similarly joined to a point forming the other terminal of the condenser. The result of this construction is to give two conducting surfaces of large area separated from each other by a thin insulating medium.

79. Capacity of Condensers.—The amount of electricity that a condenser is capable of receiving when its terminals are subjected to a certain difference of potential determines the capacity of the condenser in exactly the same manner as the amount of gas that could be forced into a vessel under a given pressure would determine the capacity of the vessel. The analogy can be carried further by stating that the amount of gas that can be forced into a given chamber will vary directly as the pressure which is applied in forcing the gas into the chamber, and that the amount of charge which a given condenser will receive will vary directly as the electric pressure between the condenser terminals.

The capacity of a condenser varies directly as the size of its conducting surfaces, inversely as the square of the distance between the conducting surfaces, and also depends upon the character of the insulating medium or dielectric between the conductors. The unit of capacity is called the farad, in honor of Michael Faraday, the celebrated scientist. A condenser having a capacity of one farad would have its terminals brought to a difference of potential of one volt if a current of one ampere flowed into it for a period of one second; in other words, the terminals of a condenser having a capacity of one farad would have a difference of potential of one volt when the condenser has a charge of one coulomb of electricity.

80. Specific Inductive Capacity.—In the preceding paragraph it was stated that the capacity of a condenser depended, among other conditions, upon the character of the insulating medium between the conductors. Some insulating mediums are better adapted to allow inductive action through them than others, and the extent to which a substance possesses this quality is called its specific inductive capacity. As an illustration, assume two condensers having plates of equal size and at equal distances apart; if the dielectric in one of them is dry air, while in the other it is paraffin, it will be found that the latter condenser has just twice the capacity of the former. The specific inductive capacity of dry air is always taken as unity; it is lower than that of any other known substance, excepting, perhaps, hydrogen. Inasmuch as a given thickness of paraffin is capable of allowing twice as much electrostatic induction through it as the same thickness of dry air, its specific inductive capacity is 2. That is, a given condenser whose conducting surfaces are separated by a certain thickness of paraffin will have twice the capacity that it would have if the same thickness of air were used in place of the paraffin.

The following table gives the specific inductive capacities of several of the more common insulating materials:

TABLE OF SPECIFIC INDUCTIVE CAPACITIES.

Air	1.000.
Paraffin	1.994.
India-rubber	2.221 to 2.497.
Ebonite	2.284.
Gutta-percha	2.462.
Sulphur	2.580.
Shellac	2.740.
Glass	3.013 to 3.258.

The question of specific inductive capacity plays an important part in the construction of cables for telephone and telegraph purposes, as will be described later.

81. The Effect of Capacity on Alternating Currents.—If a condenser *C* is placed in the circuit of a generator *G* of alternating currents, as shown in Fig. 30, its terminals will be subjected to electromotive forces varying rapidly from a maximum in one direction to a maximum in the other direction.

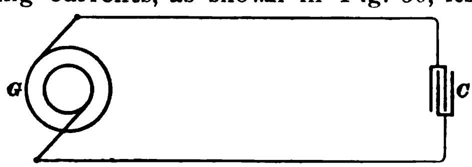

FIG. 30.

As the condenser receives a charge from the lines or discharges itself back into the line, currents will flow into or out of it, according to whether the pressure at its terminals is increasing or decreasing. The phase relation between the current flowing in or out of the condenser and the electromotive force of the line is somewhat difficult to understand. For the purpose of illustrating it, reference will be made to Fig. 31, in which G is a

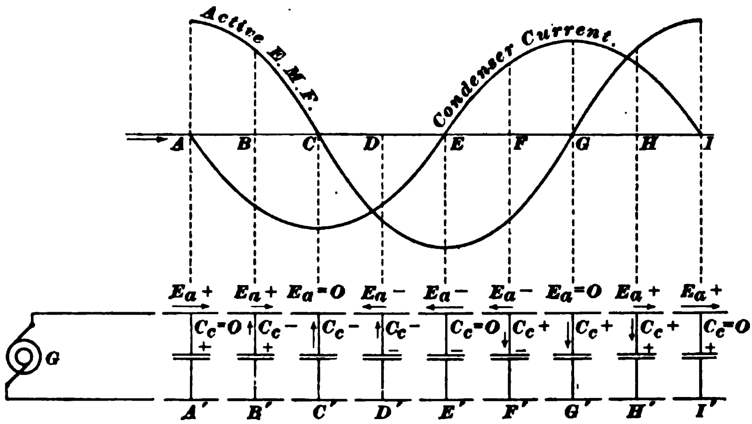

FIG. 31.

source of alternating current, the wave form of which is that of a sine curve. The two plates of a condenser are shown connected across the two sides of the line at A', and in order to illustrate the conditions throughout a complete cycle of the current, the same condenser is shown at successive points, such as B', C', D', E', etc., these points being under the corresponding points A, B, C, D, E, etc., on the horizontal line of the current and electromotive force curves directly above. One of the curves, as indicated, represents the rise and fall of the active electromotive force, while the other represents the corresponding values of the condenser current.

It should be remembered that *the amount of current flowing into or out of the condenser depends upon the rate of change of the electromotive force at its terminals; but the amount of the charge in the condenser depends on the instantaneous value of the electromotive force and not on its rate of change.* Evidently, as long as the electromotive force at the condenser terminals does not change, no current will flow into or out of the condenser, but if the electromotive force across the condenser terminals is gradually raised, current will flow into the condenser, and if gradually lowered, current will flow out of the condenser. The faster these changes in the potential across the condenser terminals take place, the greater will be the current flowing in or out of the condenser.

82. Phase Relations.—Consider now the conditions at the instant represented by A on the curve diagram and at A' in the lower part of the figure. At this instant, E_a, the active electromotive force, is a maximum and is positive, all currents or electromotive forces above the horizontal line, being considered positive and all those below it negative. The upper plate of the condenser is positive and at the same potential as the upper conductor of the circuit. At this instant, the electromotive force is undergoing no change, it being just at the turning-point between the increase and the decrease; consequently, the condenser is fully charged, but no current is flowing in or out of it. The current flowing in the line, being in phase with the active electromotive force, is at this instant a maximum, and its direction is indicated by the horizontal arrow above the point A'. It is evident, therefore, that while the active electromotive force is a maximum, the condenser current is zero, and therefore the curve representing the condenser current passes through the horizontal axis at the point A. At the time represented by the point B on the horizontal axis, E_a is smaller than before, but still positive. The top condenser plate is therefore still positive, but at a lower potential than at the point A'. From this it follows that the condenser can not now hold all of its previous charge, and therefore current must flow out of it and into the line, as indicated by the small vertical arrow above the point B'. This current is in an opposite direction from that which would flow from the generator G through the condenser path were the condenser short-circuited, and is therefore clearly of an opposite sign to that of the line current. Inasmuch as the line current is still positive and in a direction indicated by the small horizontal arrow above B', the condenser current must be negative, i. e., flowing out of the top plate, as indicated by the arrow above point *B'*, and therefore the point on the condenser-current curve at that instant is below the horizontal axis.

83. At the instant represented by the points *C* and *C'*, the active electromotive force is zero and is undergoing its maximum rate of change. The top condenser plate is neutral, i. e., it has no charge, but is rapidly decreasing towards a negative value. Therefore, since the potential of the top plate is still decreasing, current must be flowing out of it, as indicated by the vertical arrow, and as E_a is changing at a maximum rate, the condenser current at this point is a maximum. At the points represented by *D* and *D'*, the active electromotive force has changed from a positive to a negative direction, as is indicated by the small horizontal arrow. This same electromotive force may now be said to be increasing in a negative direction, or, what is the same thing, decreasing in a positive direction. The subject will be made somewhat clearer by considering it in the latter light, that is, by considering the change of the active electromotive force from the positive maximum to the negative maximum to be one steady decrease, and likewise the change from the negative maximum to the positive maximum to be one steady increase. The active electromotive force at *D* is then still decreasing. The direction of the current in the line is indicated by the horizontal arrow above the point *D'*. The potential of the top condenser plate is now negative, and therefore lower than the potential was at the time represented by the point *C*. Current is therefore still flowing out of the condenser, although the value of the condenser current is not as great as at the preceding point. It will now be noticed that the points on the two curves are on the same side of the horizontal axis, signifying that the line current which is in phase with the active electromotive force and the condenser current are in the same direction. At the point *E*, the active electromotive force reaches its maximum negative value, and ceases to decrease. Current in the line is a maximum and the upper plate has its maximum negative charge, while the condenser current is zero, because the active electromotive force is at this instant undergoing no change. So far, the condenser current has been entirely in a negative direction, and by reference to the corresponding active electromotive force curve, it will be seen that the active electromotive force has during this time been steadily decreasing. After the time represented by the point *E*, the active electromotive force begins to increase, and until the time represented by the point *I* is reached, this increase continues. During this time, the potential of the top condenser plate is gradually raised, allowing the condenser to receive more and more charge, the charge changing from a negative maximum value at *E* to zero at *G*, then to a maximum positive value at *H*, and therefore causing a continuous flow of current into the condenser, this current reaching a maximum value at the time represented by the point *G* when the active electromotive force is undergoing its maximum rate of change.

84. Angle of Lead.—Reference to the two curves in Fig. 31 will show that the condenser current is zero when the active electromotive force, and therefore the active current, is a maximum, and that the condenser current is a maximum when the active current is zero. This indicates a difference in phase between the condenser current and the active current of 90°, and a further inspection of the curve will show that the condenser current is in advance of the active electromotive force by that amount. Thus, at the point *A*, the condenser current is zero, and is decreasing; at the point *C*, which occurs later than the point *A*, the active electromotive force is zero and is decreasing. The condenser current therefore reaches this zero-point while decreasing, a quarter of a cycle before the active electromotive force or active current. A comparison of any other similar points on the two curves will show that the condenser current always reaches a certain value just 90° in advance of the active electromotive force or current. It is therefore said that the condenser current leads the active current by an amount equal to 90°. The electromotive force which is in phase with the condenser current is called the condenser electromotive force, and is of course 90° in advance of the active electromotive force.

85. It must be remembered that the active electromotive force is not the same as the impressed electromotive

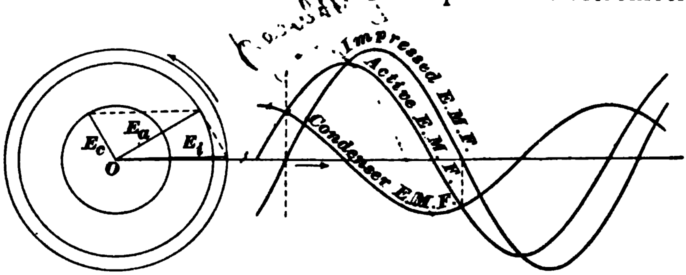

FIG. 32.

force, which is that impressed upon the line by the generator G. The active electromotive force is the resultant of the impressed electromotive force and the condenser electromotive force. This relation is shown in Fig. 32, where the curve of active electromotive force is generated by the revolution of the line E_a about the center point O, and the condenser electromotive force is generated by the revolution of the line E_c about the point O in unison with the line E_a. The line E_a represents the maximum value of the active electromotive force, and the line E_c the maximum value of the condenser electromotive force, the latter being drawn at right angles to the former, since there is a phase difference of 90° between them, and in advance of E_a, since E_c is ahead of it in phase. The curve of the impressed electromotive force is found by making the ordinates of the points on it equal to the algebraic difference of the corresponding ordinates of the active electromotive force and the condenser electromotive force, in exactly the same manner as the curve of impressed electromotive force was determined in Fig. 29.

The position of the line E_t generating the curve of the impressed electromotive force may be found by completing the parallelogram of which E_c forms one side and E_a the diagonal, as shown at the left-hand portion of Fig. 32. The length of this line and its position show the maximum value of the impressed E. M. F., and also its phase relation with respect to the active electromotive force. The effect of the condenser may be clearly seen from the parallelogram. If the condenser were not present, E_c would be equal to zero, and the impressed E. M. F. would be in phase with and equal to the active E. M. F. When the condenser is present, however, the effect of its E. M. F. is to bring the active electromotive force ahead of the impressed electromotive force in phase. This difference in phase is represented by the angle between the line E_a and the line E_t, and is called the **angle of lead,** or **angle of advance.**

DISTORTION OF TELEPHONIC WAVES.

86. Effect of Resistance.—It has been shown that the effect of resistance when not modified by self-induction or capacity is the same upon alternating or rapidly fluctuating currents as it is upon direct currents. It serves merely to reduce the amplitude of the wave without modifying its form. The electromotive force necessary to overcome resistance produces a current which serves only to heat the conductor through which it flows. This effect causes no lag or lead in the current wave behind the impressed electromotive force, acts on currents of all frequencies in exactly the same manner, and does not therefore serve to impair clearness of articulation. Telephonic communication can be successfully carried on through a circuit having a resistance as high as three megohms or 3,000,000 ohms, if the circuit has no self-induction or electrostatic capacity, and as this resistance is many times higher than that over which it is ever required to commercially transmit speech, it follows that the resistance alone of a circuit is not in itself a serious obstacle to telephonic transmission.

87. Effect of Self-Induction.—If resistance alone is present in a circuit, without self-induction, we have seen that the current will keep in phase with the impressed electromotive force, and will suffer only diminution in amplitude in direct accordance with Ohm's law. When self-induction is added, however, the electromotive force set up by it causes the current to lag behind, and also serves to further reduce the amplitude of the current; for the impressed electromotive force has not only to overcome the ohmic resistance of the circuit, but also the electromotive force of self-induction.

88. If telephone currents followed such a simple law as simple harmonic motion, the lag in the current behind the impressed electromotive force would not be such a serious matter, and would serve only to diminish the amplitude of the waves without destroying the form. The lag in the current would amount to merely shifting the entire current curve so that its various values occur slightly later than the corresponding values of the impressed E. M. F., but this shifting would not produce any changes in the actual form of the wave. Telephone currents do not, however, as we have seen, follow such a simple law, but are made up of a number of simple waves having different amplitudes and different frequencies. Unfortunately, self-induction causes a greater diminution in the amplitudes of the waves of high frequencies than in those of low frequencies, and also a much greater angle of lag. Therefore, vibrations of low frequency meet with less effective resistance than those of high frequency. The apparent resistance offered to an alternating current by a circuit having self-induction or capacity, or both, in addition to the so-called simple ohmic resistance, is called its *impedance.* The impedance of a circuit possessing resistance and self-induction for a simple sine-wave current is expressed by the following formula:

$$\text{Impedance} = \sqrt{R^2 + (2\pi n L)^2}, \qquad \textbf{(3.)}$$

in which R is the simple resistance of the circuit in ohms, $\pi = 3.1416$, $n =$ number of complete periods per second, or the frequency, and L = coefficient of self-induction—often called simply self-induction—expressed in henrys. From the fact that the current in an alternating-current circuit is equal to the electromotive force divided by the impedance, i. e.,

$$C = \frac{E}{\sqrt{R^2 + (2 \pi n L)^2}}, \qquad (4.)$$

it can be easily shown that a given circuit possessing self-induction reduces currents of high frequency more than those of low frequency; for the larger the value of n in the above expression, the smaller will be the value of the current C.

Thus, in a wave which is the resultant of waves of several different frequencies, the amplitude of the high-frequency waves will be reduced to a greater extent than those of low frequency; that is, in a current wave caused by a sound, the higher the overtones the more they are reduced in amplitude.

Furthermore, high-frequency currents lag more than those of low frequency. This can be readily seen from the formula

$$\tan \Theta = \frac{2 \pi n L}{R}, \qquad (5.)$$

which expresses for a simple sine curve the relation between the tangent of the angle of lag Θ and the frequency, self-induction, and simple resistance of the circuit. These two formulas show that the higher overtones in a complex wave are reduced more in amplitude and are displaced more in their relative position to the lower overtones and the fundamental than are the lower overtones. These two results of self-induction produce very serious deformations of current waves, and, when present to too great an extent, render the transmission of speech too indistinct to be understood at all.

89. Effect of Capacity.—A condenser placed across a telephone circuit produces a displacement in phase in the opposite direction from that produced by self-induction.

The effects produced are similar to those produced by self-induction, namely, a distortion of the wave and a reduction of the amplitude. The distortion of the wave is caused by the unequal effect of the capacity on the various component waves in the voice currents. The waves corresponding to the higher overtones are given a smaller lead ahead of their impressed electromotive forces than those corresponding to the lower tones, and are, moreover, reduced in amplitude to a less extent. Contrary to the case of self-induction, capacity in a circuit serves to give the current waves of the higher overtones a smaller phase displacement than those of the lower, and also to give them a smaller proportional reduction in amplitude.

The impedance of a circuit possessing only resistance and capacity is expressed, for a simple sine alternating current, by the formula

$$\text{Impedance} = \sqrt{R^2 + \left(\frac{1}{2\pi n Q}\right)^2}, \qquad (6.)$$

in which Q is the electrostatic capacity in farads, the other letters having the same meaning as given in Art. **88.** The tangent of the angle of lead is given by the expression

$$\tan \Theta = \frac{1}{2\pi n Q R}. \qquad (7.)$$

These two formulas show that the higher overtones in a complex wave, such as would be caused by a vowel sound, for instance, are reduced less in amplitude and are displaced less than are the lower overtones; for evidently the current which is given by the formula

$$C = \frac{E}{\sqrt{R^2 + \left(\frac{1}{2\pi n Q}\right)^2}} \qquad (8.)$$

becomes larger, and the tangent of the angle of lead, $\left(\frac{1}{2\pi n Q R}\right)$, becomes smaller the larger n becomes. These two effects produce, as in self-induction, but in the opposite direction, very serious deformations in the current waves, and are, therefore, very detrimental to good transmission of articulate speech.

The above formulas for capacity apply to circuits in which the condensers are in series with the line and other apparatus. Distributed capacity which can not be treated in this manner produces effects which will be considered later under "Electrical Properties of Telephone Lines."

90. Effect of Combined Resistance, Self-Induction, and Capacity.—For any given frequency of alternating currents, the effect of self-induction of the circuit may be neutralized by the application of a capacity of the proper value. That this is true may readily be seen by comparing Figs. 29 and 32. In the former figure, the self-induction present has caused the active electromotive force E_a to lag about 30° behind the impressed electromotive force E_i. In the latter figure, the electromotive force due to capacity has caused the active electromotive force to advance in phase ahead of the impressed electromotive force by about an equal amount. It is quite evident that by properly proportioning the self-induction and the capacity of a circuit, the electromotive force of self-induction may be made to neutralize the electromotive force due to the condenser, thus allowing only the impressed electromotive force to be active in driving current through the circuit. In this case, the impressed electromotive force and the active electromotive force are the same, and the current is in phase with the impressed electromotive force, as it would be were no self-induction or capacity present.

This can also be shown by the formula for the impedance of a circuit possessing simple resistance, self-induction, and capacity. For an alternating sine curve, this impedance is expressed as follows:

$$\text{Impedance} = \sqrt{R^2 + \left(2\,\pi\,n\,L - \frac{1}{2\,\pi\,n\,Q}\right)^2}, \qquad \textbf{(9.)}$$

and the tangent of the angle of lag or lead, as the case may be, as follows:

$$\tan \Theta = \left(\frac{2 \pi n L}{R} - \frac{1}{2 \pi n Q R}\right). \qquad \textbf{(10.)}$$

These formulas assume that the resistance, self-induction, and capacity are all in series with the line and apparatus. From these two formulas, it is quite evident that the impedance becomes equal to the simple resistance, and there is no angle of lag or lead when $\left(2 \pi n L - \frac{1}{2 \pi n Q}\right) = O$. For a given circuit having a definite self-inductance L and electrostatic capacity Q, it is quite plain that this expression can be equal to zero for only one particular value of the frequency n.

In a circuit possessing resistance, self-induction, and capacity, the current may be found by the following formula:

$$C = \frac{E}{\sqrt{R^2 + \left(2 \pi n L - \frac{1}{2 \pi n Q}\right)^2}}. \qquad \textbf{(11.)}$$

This is based upon the assumption that the current wave is a sine curve.

Very unfortunately for telephone work, such a neutralization could take place, therefore, for one particular frequency only, but as telephone currents consist of a large number of currents having a wide range of frequencies, to neutralize the effects of self-induction by those of capacity for one particular frequency only would be of no avail, and, in fact, would probably make matters worse.

While it is desirable to have a reasonably loud sound given out by the receiver, clearness is also very important, perhaps more so than loudness, for the faintest speech is readily understood if it is only clear. As we have seen, a current wave corresponding, for instance, to a consonant sound, is very complex, and to *transmit this clearly it requires the preservation of all the overtones in their exact original relations to each other and to the fundamental, both in amplitude and phase.*

The great enemy in long-distance telephone transmission, as will be shown later, is distributed capacity, that is, the capacity of the line circuit itself; and it has been found, both by experiment and analysis, that the defects due to distributed capacity could only be remedied by distributed self-induction, and this has not yet proven practical. In overhead lines, and especially in cables, the distributed capacity effects are much more serious than those due to self-induction, but in the apparatus the effects of self-induction are the greater.

COMMERCIAL TYPES OF TELEPHONE INSTRUMENTS.

MAGNETO-TELEPHONES.

91. By a magneto-telephone is meant that class of instrument originated by Bell, the essential parts of which are a magnet carrying one or more coils at its extremity or extremities, a diaphragm of magnetic material mounted in proximity to the poles of the magnet, and a suitable casing and framework binding the whole structure rigidly together. Such instruments are now used almost entirely as receivers, although it has been shown that they may also be used as transmitters.

92. Importance of Mechanical Details. — The design of a receiver for commercial service should be made with fully as much reference to perfection in mechanical construction as to electrical efficiency. Almost any permanent magnet having a coil of insulated wire about it and associated with a light, soft-iron armature will act as a receiver. In fact, apparatus designed for entirely different purposes than those of the transmission of speech have often been found to work to some extent as receivers. The attention of mechanical details forms in reality the most important feature in successful receiver design, although, of course, due attention should also be paid to the question of electrical efficiency.

93. Classification.—Commercial telephone receivers may be divided into two general classes, namely, single pole and double pole, or bipolar. In the former, a permanent magnet is so arranged as to present one pole only to the vibrating diaphragm, while in the latter class, the permanent magnet is of substantially a horseshoe form, thus presenting both poles to the diaphragm. A third class might be added embracing multipolar receivers, which would include all those having permanent magnets presenting a larger number of poles than two to the diaphragm. Many attempts have been made to improve the efficiency of the receiver by thus multiplying the number of poles, but these have not proved very successful, and therefore have not come into actual practical use.

SINGLE-POLE RECEIVERS.

94. Bell Single-Pole Receiver.—By far the greatest number of receivers in use in this country are of the single-pole type, such as is shown in Fig. 33. *M* is a compound

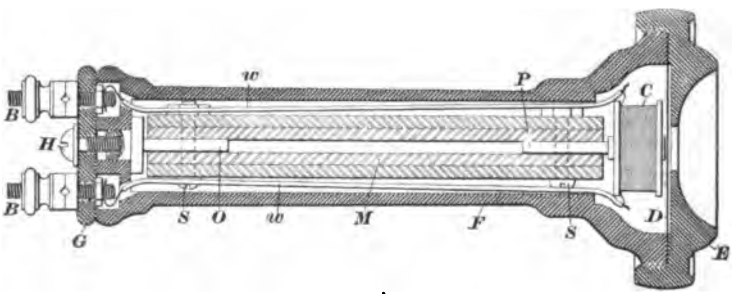

FIG. 33.

magnet composed of two pairs of permanently magnetized steel bars with *like poles together.* These pairs of bars have clamped between them at one end a soft-iron pole-piece *P*, and at the other end a block *O*, also of iron. The parts of the pole-piece *P* and of the block *O* which lie between the pairs of magnets are flattened in such manner as to present a large contact surface to the magnets which rest against them. The projecting end of the pole-piece *P* is cylindrical and has wound upon it a coil *C* of fine, insulated copper wire, usually No. 38 B. & S. gauge. The magnet and its coil are encased in a shell of hard rubber composed of three parts, *E*, *F*, and *G*. Between *E* and *F*, which screw together in the manner shown, is clamped a soft-iron diaphragm *D*, the space between the diaphragm and the pole-piece being about $\frac{1}{64}$ of an inch. This diaphragm is stamped from ferrotype metal, such as was once used by photographers in making tintypes. This metal is rolled from a very fine quality of iron, the thickness being from .009 to .011 inch. Two binding-posts *B*, *B* are secured to the tail-piece *G* of the shell, and these are connected by heavy wires *w*, *w* to the terminals of the coil *C*. The screw *H* passing through the tail-piece engages a tapped hole in a cylindrical extension of the block *O*, thus holding the tail-piece *G* in position against the shell *F*, and also firmly securing the magnets *M* to the rear end of the shell. Before putting the tail-piece in position, the binding-posts *B*, *B* are secured in place upon it by the small nuts, as shown, after which the leading-in wires *w*, *w* are firmly soldered to the inside ends of these posts. These wires are then cut off to the proper length and pushed through the tube of the shell as the tail-piece is placed in position. The fine-wire terminals of the coil *C* are then wrapped around the ends of the leading-in wires and soldered. The resistance of the coil of this receiver is 75 ohms.

95. Mechanical Defects.—The fact that this receiver has been almost universally used by the American Bell Telephone Company for many years has proven that it is capable of giving good and long-continued service; it is, however, subject to several inherent faults of a mechanical nature, which greatly impair its efficiency at times and cause much trouble besides. The principal one of these is due to the fact that hard rubber and steel expand and contract under the influence of heat or cold at very different rates. This causes the distance between the pole-piece and the diaphragm to vary with changes in temperature, sometimes to such an extent as to noticeably affect the talking qualities in the instrument. In cold weather, it not infrequently happens that the diaphragm will be drawn up against the pole-piece, thus rendering the receiver totally inoperative. This is technically known as freezing.

96. The Holtzer-Cabot Receiver.—Several plans have recently been devised for remedying the defect due to unequal contraction and expansion of the shell and magnet, one of which is to make the cup that supports the diaphragm of brass, and to firmly secure the magnet, pole-piece, and coil to this cup in such manner that the entire working parts of the receiver are firmly bound together by a metal whose coefficient of contraction and expansion is about the same as that of steel. Typical of this class is a single-pole receiver manufactured by the Holtzer-Cabot Company, of Boston, Massachusetts, shown in Fig. 34. In

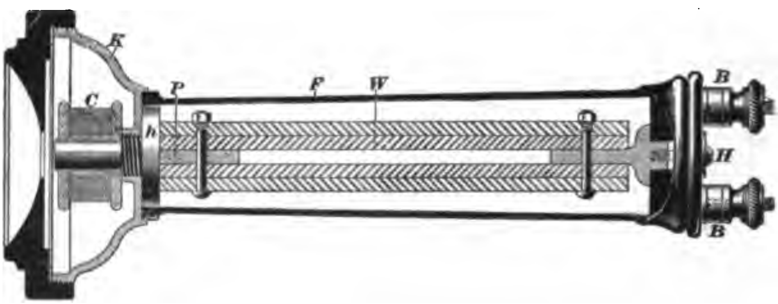

FIG. 34.

this the compound permanent magnet is made up of bars of magnetized steel in exactly the same manner as in the Bell receiver. The pole-piece *P*, which is clamped between these bars in exactly the same manner, is provided with a cylindrical head *h*, and with a screw-threaded portion adjacent to it. The brass cup *K* is provided with an internal screw-thread adapted to engage that on the pole-piece, so that when the cup *K* is secured in position, it rests firmly against the cylindrical head *h* on the pole-piece, and may be prevented from screwing off by a small pin or rivet. The tubular portion *F* of the shell rests within a shouldered portion of the cup *K*, as shown, and is held in place by a screw *H* engaging a block on the magnets, as in the Bell receiver. The method of attaching the binding-posts and of making the connections with the coil is also practically the same as in that type. These metal-head receivers, as they are called, effectually remedy the difficulties spoken of, and when once properly adjusted at the factory, need no further adjustment, and therefore no means of adjustment are provided. This has the advantage that it prevents meddlesome or ignorant persons trying to improve the operation of a receiver by altering its adjustment.

BIPOLAR RECEIVERS.

97. Bell Pony Receiver.—The bipolar receiver, recently put into extensive use by the Bell Company, is shown

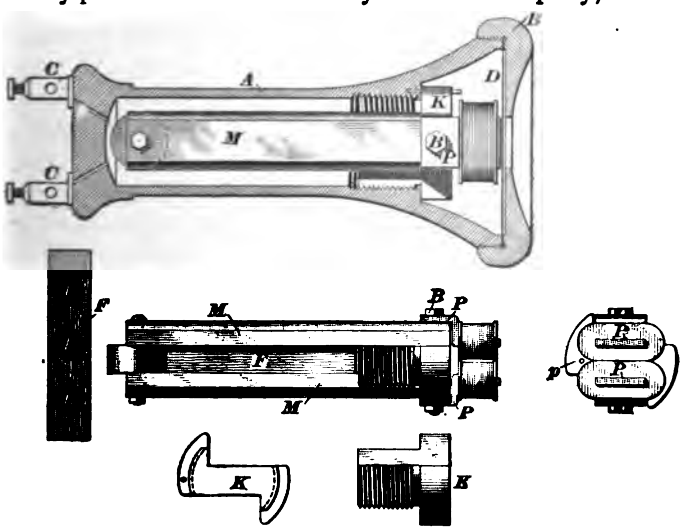

FIG. 35.

in Fig. 35. In this the magnet *M* is composed of two bars of magnet steel approximately four inches in length, secured to a small cylindrical iron block at their rear ends by a bolt, as clearly shown. In this case, opposite poles of the magnet are placed together, thus making the two bars form a complete horseshoe magnet, the poles being at the two free ends. Between the polar ends of this horseshoe magnet is clamped a brass adjustment block *K* of the form shown in the two small detached cuts in the lower part of Fig. 35. On the outside of the polar extremities of the magnet are clamped two soft-iron pole-pieces *P*, *P*, these being secured to the magnet by the same bolt *B* which clamps the magnets to the block *K*. Upon the flat pole-pieces are forced brass or German-silver washers adapted to fit tightly in place, and thus retain their position. In this manner, the spools are formed upon which the wire of the coils is wrapped. Before wrapping on the wire, however, the spool is thoroughly insulated with paper, which is fastened around the core and to the inside of the metal heads with shellac.

The shell is of two pieces *A* and *B*, which clamp the diaphragm *D* between them in the usual manner. In the piece *A* of the shell is cut an internal screw-thread into which the screw-thread on the brass block *K* fits. The block is turned within the shell *A* until the proper adjustment between the diaphragm and the pole-pieces is obtained, and is secured in that position by a pin *p*, which passes through the shoulder on the block and into the hard rubber, as shown. This maintains the adjustment permanent and prevents meddlesome persons from unscrewing the magnets. The rear end of the magnet is not supported in the shell, and inasmuch as the only support of the magnet in the shell is at a point comparatively close to the diaphragm, no trouble has been experienced due to the unequal expansion or contraction, as in the cases where the magnet was supported in the shell at the end farthest from the diaphragm. The leading-in wires are soldered to the binding-posts *C*, *C*, which are then secured in position on the shell by means of screws passing through flanges on the binding-posts and into the hard rubber of the shell. The wires are led through recesses between the block *K* and the shell to the coil chamber, and the fine-wire terminals of the coils are soldered to them in the ordinary manner. This receiver is exceedingly neat in appearance, efficient in operation, and convenient to handle; it is considerably smaller than the single-pole receiver of the Bell Company, and has proven in every way superior to it.

98. In order to give this receiver sufficient weight to operate the switching devices usually provided with complete telephones, it was found necessary to place between the limbs of the magnet a block of wood *F* containing several small lead cylinders *L* previously molded into the wood. Receivers of this type present both a north and a south pole to the diaphragm at a point very near its center. The magnetic circuit of the permanent magnet is therefore made practically complete by the diaphragm, the only air-gap being that between the diaphragm and the pole-pieces. In this way the field in which the diaphragm operates is greatly strengthened, and a slight movement of the diaphragm towards the pole-pieces produces a shorter air-gap and therefore a better path for the magnetic lines from one pole-piece to the other, and consequently a stronger pull than would be the case with the same current in a single-pole receiver.

The coils on receivers of this kind are connected together in series and possess a joint resistance of 100 ohms for ordinary exchange working, and of about 20 ohms or less when used with some of the later exchange systems of the Bell Company.

99. Western Telephone Construction Company's Receiver.—Fig. 36 shows a receiver of the Western Telephone Construction Company, which is almost identical with that of the Bell Company, with the exception of the method of attaching the receiver cord and the establishing of the connections between its conductors and the wires leading from the coils. The shell is composed of three parts *A*, *B*, and *C*, all of hard rubber, as shown. The leading-in wires *w* terminate in two small washers *a*, *a*, secured directly to the piece *A* of the shell. The receiver cord is provided with similar washers *b*, *b*, adapted to be held in contact with the washers *a*, *a* by means of the screws *c*, *c* passing into the

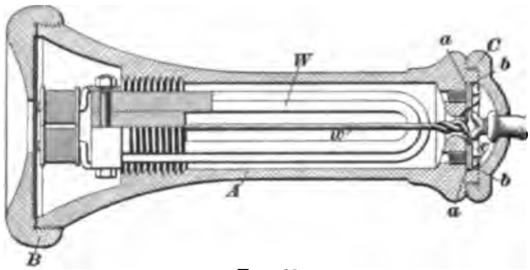

FIG. 36.

hard rubber. The receiver cord is also provided with a shoulder or enlargement at a point near to the terminals, this being of such a size that it will not pass through the opening in the tail cap *C*. This cap is slid on to the cord from its free end, and, after the cord has been connected to the receiver terminals, is secured to the part *A* of the shell by means of a screw-thread. This arrangement effectually prevents any strain coming on the cord terminals or the connectors when the receiver is dropped or hung by the cord. Such strains as these often cause breakage at the terminals of the cord, thus rendering the receiver inoperative.

100. The Ericsson Receiver.—An excellent type of receiver, manufactured in Sweden by the L. M. Ericsson Company, of Stockholm, but imported into this country to

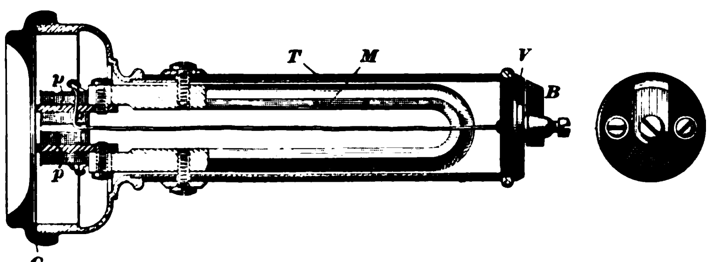

FIG. 37.

a considerable extent, is shown in Fig. 37. This is of the bipolar type and possesses probably the strongest magnets of any instrument on the market. The magnets are formed of a single bar of steel *M* bent into horseshoe form. These carry pole-pieces of soft iron secured directly to the magnet ends by means of small machine-screws. The cup containing the coils is of brass, and is secured to a thin brass tube *T* encasing the magnets. Over this tube is tightly fitted a thin hard-rubber tube serving as a handle. The magnets are secured within the shell by means of two fillister-head machine-screws projecting through slotted holes on the opposite sides of the tubular portion of the shell and engaging tapped holes in the magnet itself. The binding-posts are mounted on a hard-rubber block *V*, which is screw-threaded into the end of the brass tube *T*. Heavy leading-in wires are soldered to these binding-posts on the inside of the block *V*, and are secured to the terminals of the coils in a manner already described. The diaphragm is of tinned sheet iron, and is secured in place by means of the hard-rubber cap or ear-piece *C*.

This receiver is exceedingly durable and efficient. The fact that the shell is almost entirely of metal assures a permanent adjustment of the parts when once properly secured.

WATCH-CASE RECEIVERS.

101. A form of telephone receiver invariably used by the operators at all telephone exchanges is the watch-case receiver, one of which is shown in Fig. 38. The illustration shows a plan view with cover and diaphragm removed, and a sectional view with those parts in their normal working positions.

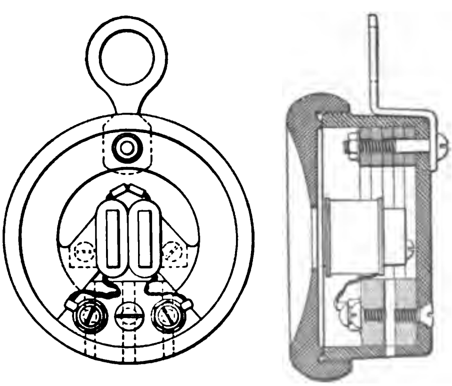

FIG. 38.

This is a double-pole receiver, and one of the soft-iron cores attached to each end of the permanent magnet protrudes through each coil. The magnet consists of three parallel pieces, and all are placed with their like poles together. The magnets are circular in form, embracing an arc of about 275°. The terminals of the coils are led to two binding-posts which are wholly contained in the hard-rubber case.

FIG. 39.

Watch-case receivers are generally double-pole, but not always. They are quite light in weight, generally under 5 ounces, and can be readily held to the ear by a spring head-band, which makes them especially suitable for the use of the exchange operators. Fig. 39 shows a Holtzer-Cabot watch-case receiver and head-band complete, ready to be placed upon the head, so that the receiver shall be held against and cover the ear to exclude sounds coming from external sources.

MULTIPOLAR RECEIVERS.

102. Many attempts have been made to improve the general efficiency of the receiver by increasing the number of magnet poles presented to the diaphragm. One of these attempts, due to a European inventor, is shown in Fig. 40. In this, two ring-shaped magnets are placed at right angles to each other, and each terminates in a pole-piece projecting through the bottom of a brass cup *c*, which forms the coil chamber. Around each one of the four pole-pieces is placed a coil similar in form to that used in the ordinary single-pole receivers. As the four pole-pieces are arranged in positions corresponding to the corners of a square, the magnetic field which passes through the diaphragm is therefore apparently doubly strengthened. The diaphragm is held in place by a screw-cap *B* engaging a thread on the cup *c*, the cap carrying a hard-rubber mouthpiece *M*. This is merely an example of many forms of multipolar receivers, and it may be said that they are more expensive to make, more complicated, and therefore more difficult to keep in order, heavier and more cumbersome, and therefore less convenient to handle. Moreover, they do not show any great gain in efficiency over the receivers of the simple bipolar type. They are not used at all in this country, and but rarely abroad.

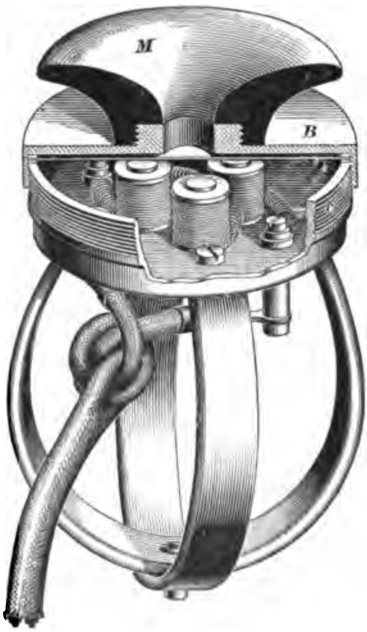

FIG. 40.

DETAILS OF RECEIVER CONSTRUCTION.

103. Magnet Steel.—The most important requisite of the permanent magnet in a receiver, or, in fact, in any telephone apparatus, is that it shall be truly permanent. Many grades of steel are capable of receiving a fair degree of magnetization, but are incapable of retaining their proper strength throughout any considerable length of time. It is very difficult to say what constitutes the best steel for making permanent magnets, but many steel manufacturers are making a special grade for this purpose, which may be purchased under the name of magnet steel.

104. After the steel has been worked into the desired form, it should be heated to a bright cherry red in a rather slow fire, so that the interior and the exterior portions will be at approximately the same temperature. It should then be quickly immersed in cold running water and constantly agitated while cooling. Care should be taken that the tongs do not prevent the water from reaching all parts of the piece at once, as this would prevent some parts of the bar from cooling as rapidly as others, and would frequently produce cracking. A high carbon steel, such as tool steel, would under this treatment become flint-hard; but very often a grade of steel which is capable of producing excellent permanent magnets will, after being thus cooled, be sufficiently soft to allow a file to make a very slight impression upon it. The practice, therefore, of judging the grade of a magnet steel by its ability to totally resist the action of a file often leads to the discarding of material admirably suited to the purpose.

105. Magnetizing.—The usual process of magnetizing consists in stroking the bars of hard steel across the poles of a powerful electromagnet. The electromagnet, if designed to be used in producing permanent magnets of various forms, should preferably have removable pole-pieces of soft cast iron, so as to accommodate itself more readily to the stroking of the different sizes and shapes of bars. In stroking, the bar to be magnetized should be held upon the poles of the electromagnet so that one of its ends rests on the north pole and the other on the south pole; it should then be drawn across the magnet face several times, always keeping it in such position as to close the magnetic circuit between the two poles of the electromagnet. For magnetizing a straight, flat bar, such as is used in the Bell single-pole receiver, the poles of the electromagnet would preferably be placed about three inches apart, so that in the case of a bar four and one-half inches long, it would lap over each pole face about three-fourths of an inch. In magnetizing a horseshoe bar, such as in the Ericsson receiver, the poles of the electromagnet would be placed about three-eighths of an inch apart, so that the two limbs of the U-shaped bar would rest, in stroking, one upon one pole and one upon the other.

106. Another process of forming permanent magnets, adopted by some manufacturing companies, consists in placing the bar of steel to be magnetized within a coil through which a powerful current of electricity is flowing. The magnetic field set up by the current in this case passes, for the most part, through the bar of steel, thus imparting to it a high degree of magnetization. Considerable trouble, however, is experienced where this process is used, in withdrawing the bar from the coil without destroying a large part of the magnetism set up in it. It is evident that inserting a bar into a coil and then turning on the current will produce a magnetizing force through the bar in one direction. Turning off the current while the bar remains within the coil tends to set up a field of force in the opposite direction, which in turn tends to counteract the effects of the magnetism already produced in the bar. The same effect is experienced, although not to so great a degree, in the case where the magnet is inserted in and withdrawn from the coil without turning off the current. This method is used to some extent, but probably the best results are obtained by the method of stroking across the poles of an electromagnet, where this method is properly carried out.

107. Cores.—The cores forming the pole-pieces of receiver magnets should be of the best quality of soft annealed iron; Swedish or Norway iron is the ideal material for this purpose, on account of its extreme softness. In the case of the bipolar receivers using a flat pole-piece, it is customary to stamp the pole-pieces from sheet iron rolled to the desired thickness. The object of using separate soft-iron pole-pieces, instead of winding the coil directly upon the end of the permanent magnet, is that soft iron is much more permeable than is hardened steel. The soft-iron pole-piece is therefore very sensitive to the magnetizing force due to a current flowing in the coil surrounding it, and therefore readily changes the pull that it normally exerts upon the diaphragm.

108. Spools.—The spool for confining the wire within its proper limits is usually, in the case of single-pole receivers, turned from boxwood or some similar hard wood, and is slipped upon the pole-piece, as shown in Figs. 33 and 34. The wires leading from the coil are usually brought out through small holes in the lower side of the spool. In case of bipolar receivers having flat coils, it is customary to form the spool as an integral part of the core itself, as shown in Fig. 41. This is done by punching the heads *a*, *a* from sheet brass or German silver and forcing them upon the pole-pieces to the positions desired. Frequently, as an additional precaution, they are soldered in place on the pole-pieces, or, instead of this, are secured by means of prick-punch marks at points along the line where the head joins the core. After the spool is properly formed, great care must be taken to insulate it in such manner that it will be impossible for the wire used in winding the coil to become short-circuited or crossed on the core. To accomplish this, the best practice is to place two thin-fiber washers *b* on the core between the two heads; these are then placed, one in contact with each head, as shown in Fig. 41, and serve as effective insulators between the wire and the heads. A thin layer of paper should be wrapped around the pole-piece between the heads, in order to keep the wire from touching the pole-piece. The terminals of the wire from the coils should never be brought out through

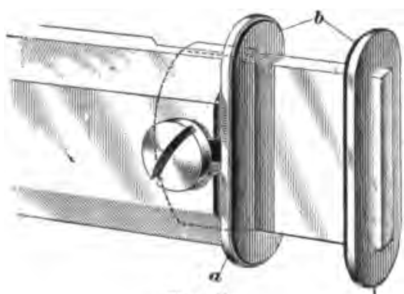

FIG. 41.

holes in the metal heads, as this practice has proved one of the most prolific causes of trouble in receiving instruments.

109. Coils.—After the spool has been formed and properly insulated, it is placed in a suitable chuck on a winding machine and wound with the desired length of silk-covered copper wire. Single-covered wire is used in preference to the double-covered, as its insulation is ample, and a greater amount of wire may be placed in a given space. As has been stated before, the resistance of single-pole receivers is usually about 75 ohms, and the size of wire either No. 36 or 38 B. & S. gauge. In double-pole receivers, the resistance of each coil is, as a rule, 40 to 50 ohms, making their joint resistance 80 to 100 ohms. The same sizes of wire as given above are in common use. For many of the most approved systems of exchange working recently adopted by the American Bell Telephone Company, the receivers are wound to a much lower resistance than those specified, the size of wire being correspondingly larger.

The Bell Company frequently wind both their single and double pole receivers with two parallel No. 38 wires, the wires being wound on side by side. The coils for both single and double pole instruments should be placed over the core as near the diaphragm end of it as possible, where they will produce the greatest possible change in the number of lines of force passing out of the iron core into the air-gap and diaphragm.

110. Shells.—The advisability of so designing the receivers as to avoid the possibility of the unequal contraction and expansion of the shells and magnets causing the distance between the diaphragm and pole-piece to vary, has been referred to in considering the various types of commercial receivers. The practice of making the receiver shell partially of brass, with a view to remedying this evil, is to be commended, although it may be said that hard-rubber shells, when a proper method of supporting the magnet is used, are thoroughly reliable and in every way satisfactory.

111. Substitutes for Hard Rubber.—Many manufacturing concerns have used to a large extent cheap substitutes for hard rubber. Without exception, these materials have proved that their sole advantage was in their cheapness. They are usually brittle, and many of them gradually warp or otherwise change their shape during hot weather, thus permanently spoiling the adjustment of the receiver. Again, many of these substances possess the quality of slowly absorbing moisture, which renders their insulating qualities poor, besides gradually destroying the black finish of the surface. It may be said that any receiver using an imitation of hard rubber in any of its vital parts should be carefully avoided.

112. Binding-Posts.—The question of properly securing the binding-posts and also making the electrical connections to them is a simple one, but when improperly attended to always produces much trouble. One of the most approved binding-posts and the method of attaching it to the shell is shown in Fig. 42. In this, S is the stem of the post provided with a shoulder s adapted to abut against the hard rubber of the shell; the inside stem extends through the hard rubber and is screw-threaded to receive a nut for securing it in place. A small hole is preferably drilled in the inner end of this stem for the reception of the heavy leading-in wire, which is soldered in place after being inserted. C is a collar adapted to slide loosely on the upper part of the stem, and N is a thumb-nut adapted to press the collar C firmly against the cord terminal inserted into the hole O through the main stem. Great attention should be paid to preventing the binding-posts from twisting in their places, as this action often causes a short circuit by allowing one terminal

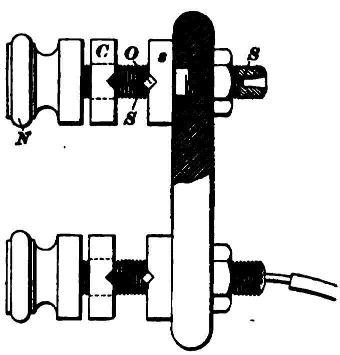

FIG. 42.

of the receiver cord to come in contact with the other. The twisting may be prevented by the insertion of small dowel-pins in the shoulders on the stem of the post, which, when the post is forced into place, enter the hard rubber. Another way of preventing this short-circuiting by the twisting of posts is by the use of a small hard-rubber block attached to the shell between the two binding-posts, such a block being shown at *B* in Fig. 37.

It is well to leave the inner ends of the stem of the post long enough to project a slight distance beyond the hard rubber, so that the hard rubber itself will not be unduly heated in soldering the leading-in wire in place. Failure to provide against this is the cause of many loose binding-posts, for when the hard rubber is heated, it softens and thus yields to the pressure exerted upon it by the inner nut.

MAGNETO-TRANSMITTERS.

113. A Typical Instrument.—While the magneto-telephone is capable of acting either as a transmitter or as a receiver, it is now used, as has already been stated, almost solely as the latter, it having been found that its practical use as a transmitter is limited to comparatively short lines. One of the best transmitters of this kind was designed by Messrs. Stromberg & Carlson, and was put on the market to a large extent several years ago. This transmitter is shown in Fig. 43. *P*, *P'* are the poles of a powerful horse-shoe magnet, usually serving also for the magnetic field of a calling generator. To these poles are secured the angular pole-pieces *k*, *k* by means of the iron screws *l*, *l'* passing through the pole-pieces, the bottom of the brass cup *h*, and into the pole-pieces of the permanent magnet. The screws *l* and *l'* are made very heavy, and therefore form a continuation of the path for the magnetic lines from the poles *P*, *P'* of the permanent magnet to the soft-iron pole-pieces *k*, *k*. Upon these poles are wound coils *m* and *m'* similar to those used in the bipolar receivers already described.

Mounted in the cap *p* by means of a screw-threaded ring *p'* is the diaphragm *d* of soft iron. This diaphragm is considerably larger and thicker than the ordinary receiver diaphragm. An internal screw-thread on the cap *p* is adapted

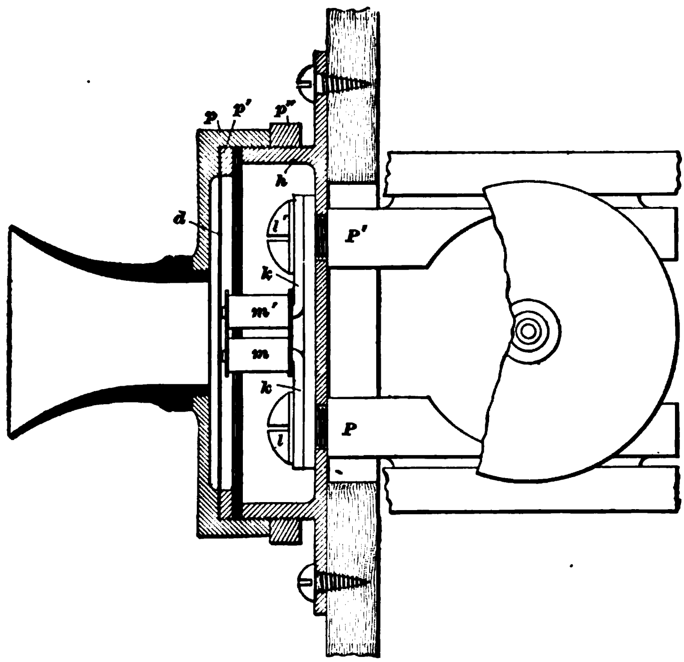

FIG. 48.

to engage an external thread on the cup *h*, so that by turning one upon the other, the diaphragm may be adjusted towards or from the pole-pieces until the proper conditions are secured. The cap may be locked into any desired position by the lock-ring screw *p''*, threaded upon the cup *h* and adapted to bind against the edges of the cap *p*. This method of adjusting the diaphragm is now employed by the Stromberg-Carlson Telephone Manufacturing Company in their receivers, and has proven entirely satisfactory.

114. Advantages and Disadvantages.—The magneto-transmitter is seemingly the ideal instrument for generating currents corresponding to the vibrations set up by the voice. They require no battery power, and when properly constructed and adjusted, need no attention whatever. They articulate exceedingly well, and their only drawback is in their lack of power, which so far has proved an insurmountable difficulty. There are at present, however, several exchanges in the United States using the instruments described above exclusively, and are apparently giving satisfaction, probably because the subscribers have never been educated to the use of the more powerful battery instruments.

MICROPHONE TRANSMITTERS.

CLASSIFICATION.

115. The various forms of commercial microphone transmitters will be considered under three separate heads, the classification being substantially the same as that adopted by the United States Patent Office.

116. Single-Contact Microphones.—These are instruments of the same general form as that shown in Fig. 26, where but a single pair of contacts is used as the variable resistance medium.

117. Multiple-Electrode Microphones.—It was not long after the invention of the microphone that many attempts at the improvement of its efficiency were made by increasing the number of pairs of contacts through which the current passes. This class is well termed multiple electrode. In some of these, the circuit is so arranged as to include the various contacts in multiple or parallel, in others so as to include them in series, and in others in a combination of the two, that is, both in series and in parallel.

118. Granular Microphones.—These are in reality a particular form of the multiple-electrode type, but are of such distinct construction as to warrant putting them in a separate class. Nearly all good commercial transmitters at the present time use granular carbon as the variable resistance medium, this idea, it will be remembered, having been conceived by Hunning

SINGLE-CONTACT MICROPHONE TRANSMITTERS.

119. The Blake Transmitter.—One of the early transmitters which came into very extensive use was that

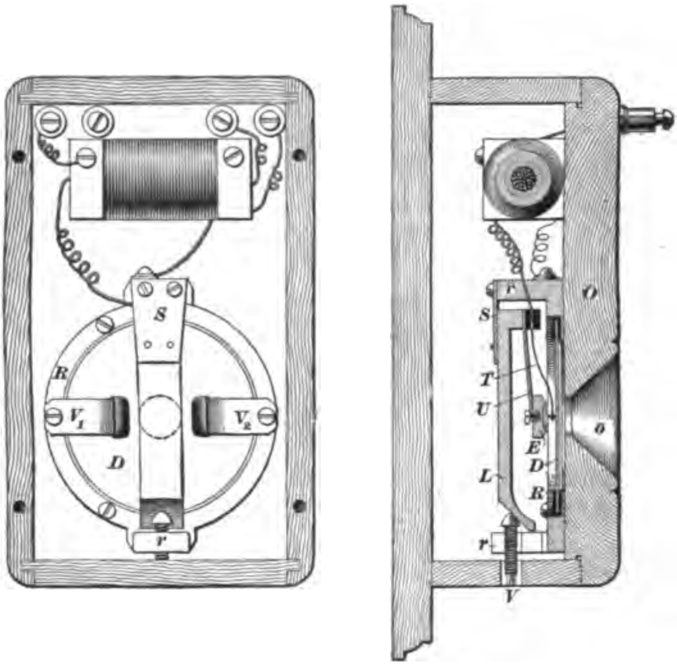

FIG. 44.

devised by Francis Blake, and shown in Fig. 44. This has been in constant use in the United States for the past 20 years, although the patent was only granted in 1881, not because it was better or even as good as many others, but because it was fairly efficient, required little battery power, was cheap, not easily put out of order, and easily repaired when repairs were needed.

Referring to Fig. 44, *O* is the front board of the transmitter box, having a suitably shaped opening *o* to receive the sounds. *R* represents a cast-iron ring, forming a framework for the instrument. It is screwed to the inside of the board *O*, and is provided with two lugs *r* and *r*, which form parts of the same casting. On a properly turned seat in this ring is mounted the diaphragm *D* of soft sheet iron, of about double the thickness of that used for receiver diaphragms. Around the edge of the diaphragm and overlapping both surfaces is stretched a soft-rubber band, serving to insulate it from the ring and at the same time to allow it freedom in vibrating. Two damping springs V, and V_1, tipped with rubber and screwed to the edge of the ring, rest lightly on the diaphragm *D*, to prevent the continued vibration of the diaphragm at its own particular rate after the sound vibrations cease to control its movements. Thus it is brought to rest immediately, and is ready to respond to the following sound waves without interfering with them by its own natural vibrations, which would cause indistinctness in the sound given out by the receiver. These also prevent too great an amplitude of vibration of the diaphragm. Often only one damping spring is used.

Flexibly mounted on the lug *r* by the spring *S* is a bent level *L*, on the upper extremity of which is mounted a spring *U*, which carries the back electrode *E*, formed of a hard-carbon button, set into a rather heavy brass block, or button. This carbon electrode is in electrical contact with the lever *L*. On an insulating block also mounted on the lever *L*, and thus insulated at this place from both it and the spring *U*, is attached a lighter spring *T* carrying at its lower end a small piece of platinum, which is held between the diaphragm and the carbon button. The normal set of the spring *T* is towards the button and away from the diaphragm, but the pressure of the spring *U*, which is much the stronger of the two, overcomes this and keeps the platinum pressed against the diaphragm. This prevents any possible parting of the carbon and platinum electrodes, which would cause a serious disturbance at the receiver. The frame *R*, which is in electrical connection with the back electrode, forms one terminal of this instrument, while the spring *T* forms the other terminal.

The adjustment of pressure between the electrodes is accomplished by turning the screw *V*, which wedges against the inclined surface on the lower end of the lever *L*, and moves it backwards or forwards in an obvious manner. In connection with the Blake transmitter, many experiments were performed trying various substances as electrodes, and it was determined that, of all easily obtainable materials, one electrode of carbon and the other of platinum gave the best results. When both electrodes were made of carbon, they seemed less apt to part and thus produce a click in the receiver due to a break in the microphone contact than when one electrode was carbon and the other of platinum, but the latter combination gave a better quality to the reproduced sound. The carbon should be hard and well polished, so as to avoid wear at its contact with the platinum. The socket of spun brass into which the carbon button is set is made heavy, so as to have considerable inertia. A light electrode, no matter how the strength of the spring is varied or adjusted, does not give near as good results. The inertia of the heavy electrode tends to prevent its velocity increasing or decreasing as rapidly as the velocity of the platinum electrode, and therefore there is a greater change in the pressure than would be the case where a constant pressure of a spring only was utilized. This transmitter, when in good adjustment, articulates well and transmits the quality of the voice with wonderful fidelity. It is not very powerful, however, and will not stand more than one cell of battery, as stronger battery power will cause the instrument to give forth a singing or sputtering sound.

120. This is one of the few transmitters using a metal for one of the electrodes. The production of the humming sound caused by too light an adjustment between the electrodes or by too great a battery power is due to what is known as Trevelyan's effect. When the current passes through the point of contact, it causes a heating, and therefore an expansion, of the particles in the contact. This forces the electrodes farther away, and thereby increases the resistance through them. This diminishes the current, and therefore lowers the temperature, thus allowing the electrodes to come closer together again. This in turn diminishes the resistance, causes an increase in the flow of current, and produces another heating effect, so that under a particular adjustment these effects take place periodically and cause the humming sound referred to.

MULTIPLE-ELECTRODE TRANSMITTERS.

121. Carbon-Ball Transmitter. — These are all modifications of the Hughes microphone. The idea of using

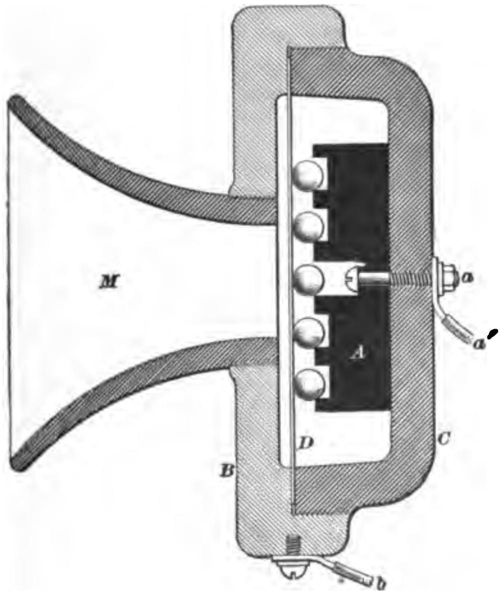

FIG. 45.

carbon balls held loosely between a back block and a vibrating diaphragm has received considerable attention. A form shown in Fig. 45 has been used to quite a large extent, and is a good example of a transmitter belonging to the multiple-electrode class. In this, *D* is a vibrating diaphragm, in this case of carbon. It is clamped between a hard-rubber cup *C* and a metal cap *B*, the latter carrying a mouthpiece *M*. Secured centrally within the cup by a screw *a* is the back carbon block *A*, having a number of cylindrical holes bored in its front surface. Within each one of these holes rests loosely a carbon ball, the space between the front surface of the block and the diaphragm being such as not to allow the balls to roll out of their sockets. Each ball, therefore, rests loosely against the diaphragm and against the back block, and therefore completes the circuit between the two. The front cap *B* is in electrical contact with the front surface of the diaphragm, and therefore may be considered as one terminal of the transmitter. A wire *b* is secured to it for making connection with one side of the local circuit. The screw *a* makes contact with the carbon block, and therefore may be considered as the other terminal of the transmitter, the wire *a'* leading from it to connect with the other side of the local circuit.

This form of transmitter is capable of giving very fair results, but has been almost entirely superseded by those of the granular-carbon type, which will be described later. This transmitter has the advantage of requiring almost no attention, if properly made, but a loud sound often causes the contact between the diaphragm and the balls to break entirely, thus producing loud and unpleasant rasping sounds in the receiver.

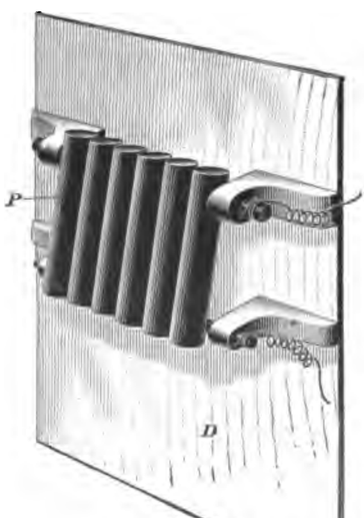

FIG. 46.

122. The Turnbull Transmitter.—This is another form of multiple-electrode instrument now very little used, but interesting and instructive as being one of the most promising instruments in the multiple-electrode class. This is shown in Fig. 46, in which *D* represents the vibrating diaphragm, usually of thin, dry wood. Secured across the upper portion of the diaphragm is a bracket carrying a horizontal rod on which a number of cylindrical carbon pendants *P* are pivoted. The lower ends of these pendants rest against a horizontal carbon rod carried on brackets at a point about opposite the horizontal center line of the diaphragm. The upper and lower brackets, respectively, form the terminals of the instrument, the circuit between them being completed through the upper pivot-rod, which is of conducting material, or carbon, thence through the several pendants in multiple to the lower carbon rod, against which the pendants rest. When the diaphragm is vibrated, the pressure on the various contacts in the circuit is caused to vary, and each one of them produces its own microphonic effect, all, however, supposedly acting in unison.

This transmitter proved exceedingly sensitive, but was open to the same objection as the carbon-ball instrument, of breaking contact on being actuated by loud sounds. Instruments of this and similar types embodying carbon pencils resting in various manners against blocks of carbon have been used to a comparatively slight extent in this country, but have met with better favor in Europe, where they are still frequently found.

GRANULAR TRANSMITTERS.

123. Western Telephone Construction Company Transmitter.—Fig. 47 represents probably the simplest form of a granular-carbon instrument in use today. The diaphragm *D* is of carbon, clamped between a front metal cup *B*, carrying a mouthpiece, and an insulating cup *C*, carrying a carbon block *A*. The insulating cup *C* is secured to the support arm *F* by two screws *f*, *f*, and the screw which holds the carbon block in place is sufficiently long to pass entirely through the insulating cup and into a tapped hole in the supporting arm. This connects the carbon block electrically with the arm, so that the latter forms one terminal of the instrument. The metallic cup *B* forms the front terminal of the instrument, and connection with it is made by means of a flexible cord *G*, as shown.

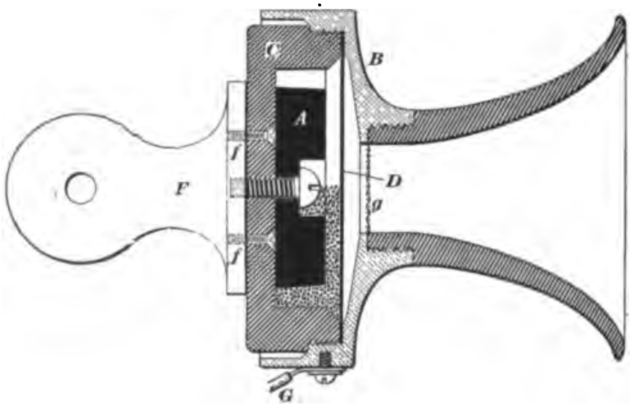

FIG. 47.

The carbon block is of such diameter as to leave about $\frac{1}{8}$ of an inch space between its cylindrical surface and the walls of the insulating cup, and of such thickness as to leave about $\frac{3}{64}$ of an inch space between the front surface of the block and the diaphragm. The chamber thus formed back of the diaphragm is just half filled with granular carbon of a comparatively coarse grain. This, of course, forms the conducting medium between the diaphragm and the back block, thus completing the circuit through the transmitter. In the vibration of the diaphragm, each point of contact between it and the various granules, between the granules themselves, and between the granules and the back block, produces a microphonic action. This transmitter is capable of giving very powerful and very distinct articulation, it, however, having the disadvantage of requiring a somewhat greater current than many other granular-carbon instruments.

All carbon-diaphragm instruments should be provided with some means of protecting the diaphragm against breakage caused by persons tapping against it with the finger or with a lead-pencil. The most common protection is in the use of the wire gauze *g* shown in Fig. 47.

124. Experiments with the Western Telephone Construction Company Transmitter.—A long series of experiments conducted with a view to determining the best proportions for this transmitter led to the adoption of the foregoing dimensions. It was thought that better results might be obtained by confining the granular carbon to contact with the center portion of the diaphragm, leaving the outer portions free to vibrate. This would seem to be true, because the central portion of the diaphragm is subject to the greatest vibration, and should therefore be able to produce the greatest changes in resistance. Moreover, it would seem that the granular carbon near the edge of the diaphragm would act merely as a dead resistance in the circuit, without being affected at all by the vibrations. It was found, however, that the best talking results were produced by allowing the granules to come in contact with the whole lower half of the diaphragm. This gave clearer and more powerful articulation, with, however, a corresponding diminution in normal resistance, which rendered a greater battery power necessary.

The carbon diaphragms used in this and similar instruments are prepared from a very fine grade of ground carbon, mixed with a suitable binder, and molded under enormous hydraulic pressure to the required form; they are then placed on edge in an iron box filled with sand, and subjected to a suitable baking at a very high temperature. Several carbon manufacturers are now able to produce these diaphragms of a uniform thickness of not over $\frac{1}{100}$ of an inch. It has been found, however, that diaphragms slightly thicker than these give the best results, the usual thickness being from $\frac{1}{64}$ to $\frac{1}{50}$ of an inch. Much depends on the grade of carbon and on the method of baking these parts, as the elasticity and conductive properties of the carbon are greatly affected thereby.

125. The Ericsson Transmitter.—This instrument, which is shown in Fig. 48, is manufactured in Sweden and imported into this country as a companion piece to the

Ericsson bipolar receiver. It is an excellent transmitter, producing a tone almost perfect in quality, and although not quite so powerful as some other instruments, sufficiently so to be used on very long lines. The diaphragm *D* is of ferrotype metal enclosed in a metallic case. It is held in its position against the forward portion of the casing by two pairs of light springs *s* bearing against four points on its rear surface. To the rear of the diaphragm is riveted a thin sheet-metal electrode *E*, which is gold-plated in order to prevent corrosion and to secure clean contact. The back electrode *C* is a cylindrical carbon block having circular grooves in its front face. Around the cylindrical edge of this block is wound a layer of cloth *c* in such manner as to

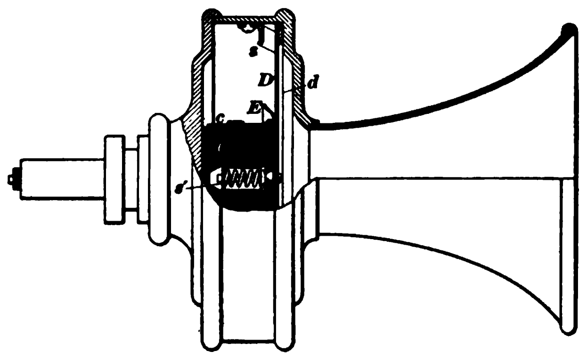

FIG. 48.

project about $\frac{1}{8}$ of an inch beyond the front face of the block. This projecting edge of cloth is frayed out so as to press lightly against the edges of the front electrode without interfering seriously with its vibrations. The chamber enclosed by this cloth is filled with granular carbon, the grains being considerably finer than those used in the transmitter already described. The cloth *c* serves not only to confine the granular carbon within its chamber, but as a damper to prevent too violent a motion of the diaphragm. An additional damper is formed by the coiled spring *s'* in the central cavity in the back block, which presses a small tuft of cotton against the center of the front electrode. In order to prevent moisture from the breath from entering the instrument, a thin diaphragm *d* of oiled silk is placed in front of the sound-receiving diaphragm *D*, and forms a moisture-proof packing between the front edges of this diaphragm and the casing. This silk diaphragm has been found not to appreciably affect the transmitting qualities of the instrument.

126. The Sutton Transmitter.—This is an instrument manufactured by the Phœnix Telephone Company. The front electrode *E*, Fig. 49, is a carbon block, of the form

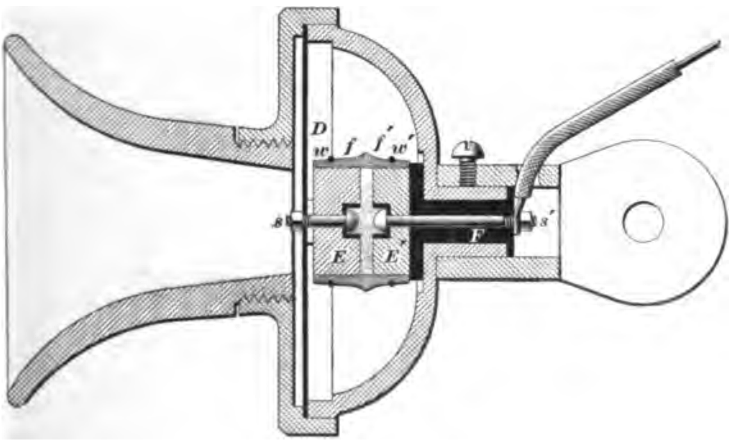

FIG. 49.

shown, secured directly to the center of the metallic diaphragm *D* by a small screw and nut *s*. The back electrode *E'* is of similar material and form, and is secured by a screw and nut *s'* to an insulating bushing *F* contained within a rearwardly projecting tubular portion of the metallic casing. Rings of raveled felt *f* and *f'* are secured, respectively, to the electrodes *E* and *E'* by the wires or strings *w* and *w'*. The abutting edges of these rings are frayed out so as to form a very flexible but continuous wall around the chamber formed between the two electrodes. This chamber is nearly filled with granular carbon, which acts under the vibration of the diaphragm in the usual manner. Although this

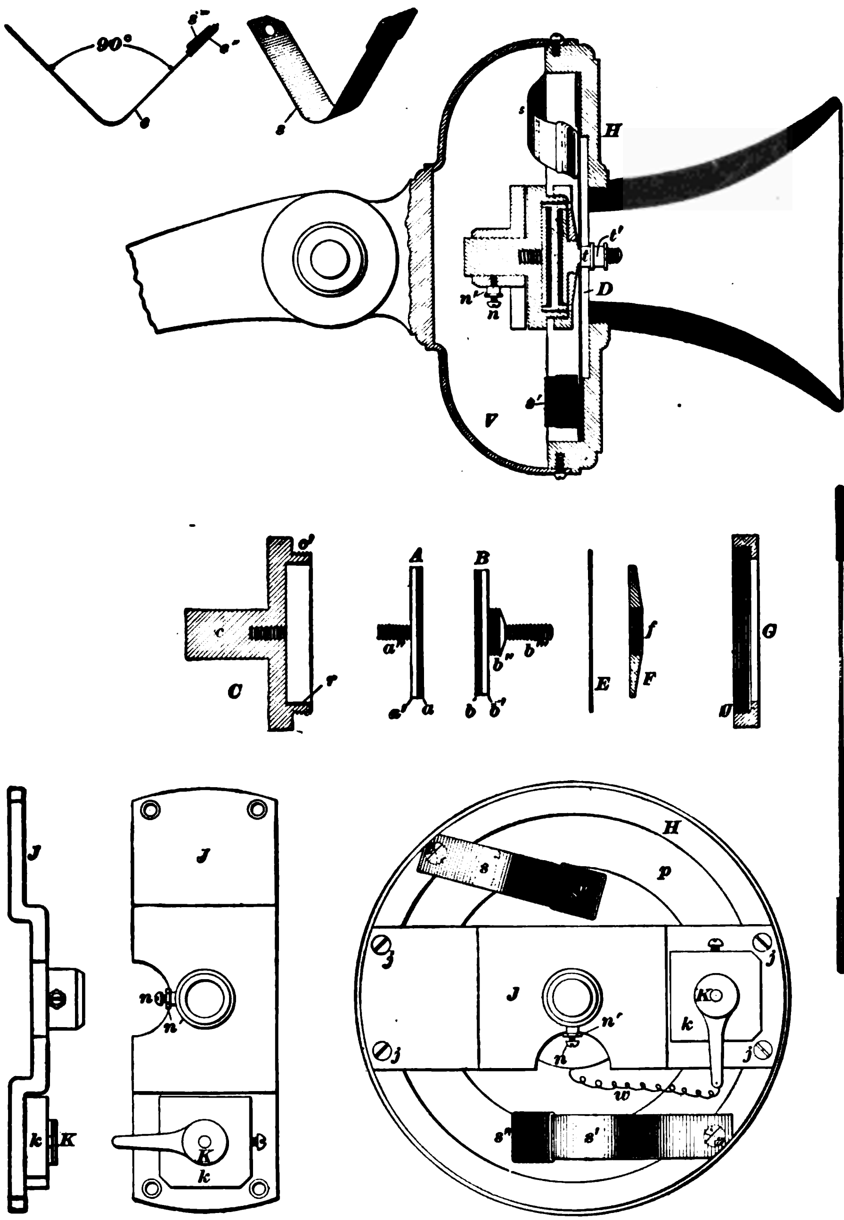

FIG. 50.

instrument is capable of producing good transmission, it is subject to the criticism that the center of the diaphragm is too heavily weighted. The electrode *E*, with its screw and nut *s* and washer holding the block away from the diaphragm, possesses considerable weight, and therefore inertia, which prevents the diaphragm from moving with as great a freedom as it would otherwise do.

127. The Solid-Back Transmitter.—Probably the most perfect transmitter in common use is the one represented in Fig. 50, designed by Mr. Anthony C. White, and used exclusively by the American Bell Telephone Company and its sub-companies. This is called the White or Solid-Back transmitter, the latter name being given it probably on account of the fact that the back electrode is rigidly supported to the frame of the instrument. This feature is also found, however, in many other transmitters.

In this figure, *H* is a rather heavy brass casting turned to the form shown. Upon this all the working parts of the instrument are mounted. *D* is a vibrating diaphragm of aluminum .022 inch in thickness and $2\frac{1}{2}$ inches in diameter. Around the edge of this diaphragm is stretched a flat rubber band *p*, $\frac{3}{4}$ of an inch wide and of sufficient elasticity to allow it to clasp the edges of both sides of the diaphragm, as shown in the sectional views. The diaphragm is held in its seat on the inner surface of the casting *H* by two damping springs *s* and *s'* secured to the edge of the casting *H* at diametrically opposite points by screws; and each of these springs is tipped with a piece of soft-rubber tubing *s''*, so that the springs will not come in metallic contact with the diaphragm. The tip of the spring *s* is also provided on its under side with a small felt cushion *s'''*. The spring *s'* bears against the diaphragm at a point nearly half way between its edge and center. The spring *s'* bears also against the diaphragm, but at a point much nearer its edge, so that it rests upon the rubber ring *p*. The damping springs *s* and *s'* are of spring steel $\frac{1}{100}$ of an inch thick and $1\frac{7}{16}$ inches long, bent normally at right angles at their center points, as is shown in detail in the upper left-hand portion of Fig. 50.

128. The parts of the instrument forming the variable resistance device are separately shown, considerably enlarged, in the central portions of Fig. 50. These parts when assembled, form what is termed the variable resistance button of the instrument, which is complete in itself, so that it may be entirely removed and replaced by another, in case the transmitter needs repairs. The back electrode *A* is composed of a carbon disk *a* secured to a flat brass disk *a'* forming the head of a screw *a'*. This electrode is secured in position in a chambered block *C* of brass by means of the screw *a'*. The diameter of the electrode *A* is somewhat smaller than the internal diameter of the chamber in the block *C*, so that a space is left entirely surrounding the electrode. The inner wall of the chamber is lined with a paper strip *r*, as clearly shown in the detail figure of the block *C*. The front electrode *B* consists of a carbon block *b* mounted in a similar manner upon a disk *b'* forming the head of the shouldered screw-threaded shaft having screw-threads *b'* and *b'''*, as shown. *E* is a mica washer adapted to fit over the shoulder *b'* on the electrode *B*, and of sufficient external diameter to close the opening in the chamber in the block *C*. This washer is held in its position against the electrode *B* by a nut *F* having an internal screw-thread *f* adapted to engage the thread on the shoulder *b'*. In assembling the button, the electrode *A* is secured in place in the block *C*, and the chamber is then nearly filled with fine granular carbon. The electrode *B*, with its washer *E* secured in place, is then laid over the opening and clamped in position by the internally-threaded collar *G*, the screw-thread *g* on which engages the external screw-thread *c'* on the block *C*.

The button, as a whole, is secured in place in the transmitter by means of the rearwardly projecting lug *c* on the block *C*, which fits in a collar in a bracket *J* secured by screws *j* to the casting *H*. The button may be clamped in any desired position by means of the screw *n* and its lock-nut n', which passes through one side of the collar J. The forwardly projecting screw b''' of the electrode B passes through a central hole in the diaphragm and is secured in position by two small nuts t and t'.

129. The back electrode A, being firmly mounted on the frame of the transmitter, is held stationary, while the front electrode, being rigidly secured to the diaphragm D, is forced to partake of all of its vibrations to and fro. This vibration of the front electrode is rendered possible by the flexibility of the mica washer E. The vibrations of the diaphragm, therefore, produce corresponding variations in pressure between the two electrodes and the granular carbon between them, thus bringing about the microphonic action in a very perfect manner. The damping springs prevent an undue vibration of the diaphragm, corresponding to some particular rate at which it might be specially adapted to vibrate.

130. The entire transmitter is supported by means of a metallic shell V, from which it is readily removed when desired. This shell forms one terminal of the transmitter, as it is in metallic connection through the frame of the instrument with the back electrode A. The other terminal of the instrument is a brass clip K mounted on a fiber block k secured to the bracket J. This terminal K is electrically connected with the front electrode by means of a fine coiled wire w. The faces of the carbon electrodes in this transmitter are highly polished and perfectly plane. The space within the chamber is entirely filled with a comparatively fine granular carbon, the granules being of a very uniform size (not more than .021 inch or less than .019 inch in diameter).

131. The Colvin Transmitter.—In order to avoid the claims of the Berliner patent, which, if valid, might cover all forms of transmitters depending for their action upon the variation in resistance between two or more electrodes in constant contact, many attempts have been made to produce a transmitter in which the variations in resistance were brought about by some other means than variations in pressure between the electrodes. The problem has been attacked from nearly all conceivable standpoints. A transmitter, resulting apparently from one of these attempts, was produced some years ago by Mr. F. R. Colvin. It is shown in Fig. 51, in which *D* is a diaphragm of aluminum, mounted loosely in the enclosing case. *A* is a cup of insulating material, in which are mounted two metallic electrodes *E* and *E'*. these are permanently held at a considerable distance apart, and never come into contact with each other. The two wires forming the terminals of the transmitter connect respectively with these electrodes, the circuit between them being completed by the granular carbon placed within the cell. The cell *A* is rigidly fastened to the center of the diaphragm by the bolt *B*, as shown, the joint between the diaphragm and the edge of the cup being hermetically sealed by the introduction of some plastic material, in order to prevent the entrance of moisture. In this, the diaphragm and cell vibrate as one unit, there being no flexible connection whatever between them, the variations in resistance being caused by the variable contacts between the granules in the path of the current from one electrode to the other. This transmitter was capable of fairly good transmission, but the results were not good enough to warrant its adoption in practice.

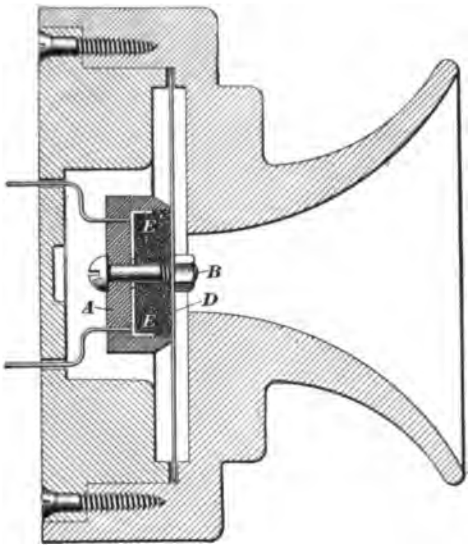

FIG. 51.

132. Other Forms of Transmitters.—So far, all the transmitters considered, with one exception, have depended for their action on changes in resistance between electrodes of which at least one in each case was of carbon, the exception mentioned being the magneto-telephone, which, as we have seen, has proved generally unsuccessful in competition with its more powerful rivals in the form of carbon transmitters. It may be said in general that although many attempts have been made in other directions, no transmitter has been produced which is to any degree satisfactory.

133. Packing of Granular Transmitters.—One of the chief difficulties encountered in the operation of granular-carbon transmitters is that known as packing. This trouble may be attributed to several causes, and in each case consists in the granules settling into a compact mass, so as not to be sensitive to changes in resistance, or, in some cases, in a wedging of the granules between the electrodes, so as to prevent all vibrations of the diaphragm. Probably the most common cause of packing is the using of carbon granules of different sizes, so that they gradually settle into a compact mass, the large ones rising to the top and the small ones settling to the bottom and filling in all the interstices between the large ones. In other cases, packing is caused by moisture entering in the carbon chamber, either from the breath or from dampness in the atmosphere. Still another cause is the wedging of several granules between the electrodes in such manner as to hold them farther apart than when in their normal position. In most cases, a thorough agitation of the granules will remove the defect, temporarily at least. If, however, it is due to moisture, the transmitter should be refilled and, if possible, means provided for preventing the entrance of moisture again.

134. In the best makes of transmitters, particular attention is paid to obtaining granules of uniform size; this is usually accomplished by sifting them through screens having a certain number of meshes to the inch. Thus, in the solid-back transmitter, only those granules are used which will pass through a screen having 50 meshes to the inch, but will be retained by a screen having 55 meshes to the inch.

As an illustration of how packing may be caused by the wedging action of the granules between the electrodes, almost any granular-carbon transmitter may be packed by placing the mouth firmly against the mouthpiece and sucking in the breath. This draws the electrodes apart and allows the granules to settle lower down in the chamber. When the pressure is removed, the electrodes tend to assume their normal position, but can not do so on account of being held apart by the granules. As a result, a considerable pressure is exerted upon them and the conditions of loose contact destroyed. After such treatment, a transmitter will usually be found to be perfectly "dead," and its efficiency can only be restored by reagitating the granules.

135. Prevention of Packing.—When granular-carbon transmitters were first introduced, the trouble due to packing was so serious as to call forth much attention on the part of inventors to produce means for its prevention. Most of these consisted in some means of mechanically agitating the granules at frequent intervals. In some, a spring was arranged within the carbon chamber of the transmitter with a trigger projecting outside of the casing, by means of which the spring might be made to vibrate among the granules, thus effectually stirring them up.

A later device, and one which came into quite general use, consisted in mounting the transmitter so as to be capable of rotation on its axis. Such a form is shown in Fig. 52. The case *B* containing all the working parts of the transmitter was journaled in the front board of the box in which the instrument was mounted by means of a cylindrical tube integral with the metallic portion of the casing. The mouthpiece, secured within this tube by means of a screw-thread in the ordinary manner, served as a handle for rotating the entire transmitter when desired. The double spring *D* made contact at two points on the outer metallic casing of the instrument, while the flat spring *E* made a pivotal contact

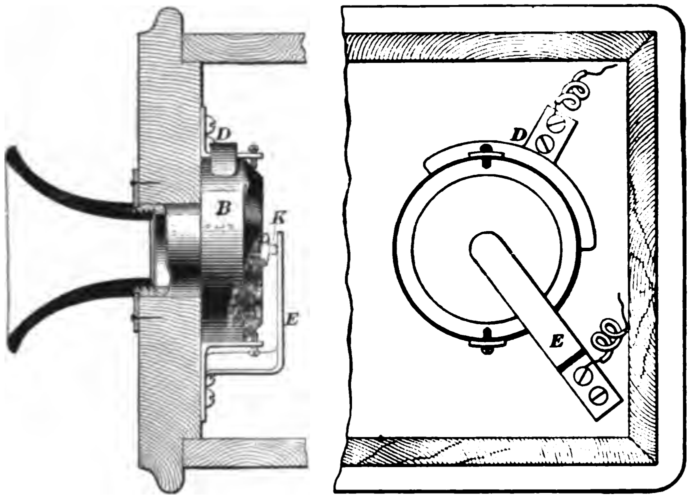

FIG. 52.

with the screw *K* connected with the back electrode. These two springs, therefore, form the terminals of the instrument. An occasional turn on the mouthpiece would bring about an entire rearrangement of all the granules within the chamber, thus effectively relieving any packing This arrangement, while answering the purpose for which it was designed, introduced two sliding contacts in the primary circuit of the transmitter—a very objectionable feature, because the corrosion of the metal surfaces between which the contact takes place, or the collection of dust between the contacts, will often cause a break in the circuit or a point of high resistance, thus rendering the transmitter practically inoperative.

136. This idea of rotating the transmitter was further developed by a number of inventors, who arranged mechanism for accomplishing the rotation automatically, the usual plan being to use a pawl, carried on the lever of the switch hook, which in its operation up and down would engage the teeth of a ratchet-wheel carried on the transmitter itself. Every time the telephone was used, the hanging up of the receiver would cause a partial rotation of the transmitter, thus always maintaining the granules in a state of loose contact. These devices, however, have gradually dropped out of use, as the later and best forms of transmitters are comparatively free from the trouble of packing. The benefits to be derived from such mechanisms are not, therefore, sufficient to offset the undesirable complexity and the disadvantages of having one or more movable contacts introduced into the circuit. The use of carbon granules of uniform size has probably been the greatest factor in improvement in the operation of transmitters, with regard to a reduction of the packing. The form of the carbon chamber also, apparently, has a considerable effect on the liability of the instrument to pack. In the solid-back transmitter, the space around the periphery of the two electrodes was left for the purpose of allowing room for expansion of the particles between the electrodes, which are directly in the path of the current, and therefore subject to a greater amount of heating than those around the periphery.

There is probably no granular-carbon transmitter that will not pack under certain conditions; but this packing can usually be remedied by giving the instrument a sharp blow from beneath with the soft portion of the hand in such a manner as to disengage any particles which have become wedged.

THE INDUCTION-COIL.

137. The induction-coil used in telephony is, almost without exception, made by winding upon a suitable spool a comparatively small number of turns of coarse copper wire, and upon the outside of this a large number of turns of fine copper wire. Within the spool is placed a bundle of soft-iron wire, forming a core. The

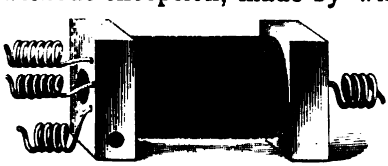

FIG. 53.

coil ordinarily used with the Blake transmitter is shown in perspective in Fig. 53 and in section in Fig. 54. The spool is formed by gluing two square wooden heads *H* upon a paper tube *T*. It is then placed upon a mandrel and wound with three layers of No. 24 B. & S. gauge, single cotton-covered wire, this forming the primary coil. Around the primary coil

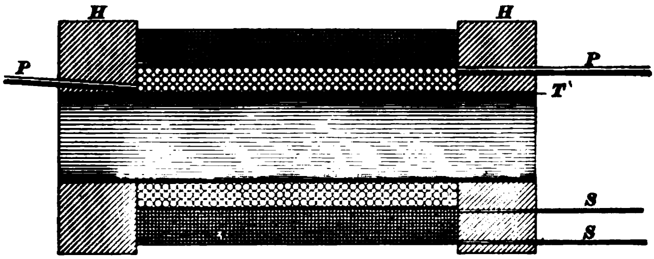

FIG. 54.

is then wound several layers of waxed paper, and upon this the secondary coil is wound, usually of No. 36 B. & S., single cotton-covered wire. The terminals of all the wires are brought out through the heads of the coil, as shown, the terminals *P*, *P* of the primary being brought out from opposite ends of the coil, while the terminals *S*, *S* of the secondary are brought out from the same end. After winding the secondary, a layer of bookbinder's cloth is wound over the coil, usually to hide defects in winding, but also to serve as a protection for the wires. The core is one-fourth of an inch in diameter and is composed of a bundle of thin, soft-iron wires cut to the desired lengths. The resistance of the primary winding in this coil is usually slightly less than one-half an ohm, while the resistance of the secondary coil is, as a rule, 250 ohms. This coil is therefore commonly spoken of as a 250-ohm coil.

138. A better construction of coil is shown in Fig. 55. In this, the spool is composed of two square fiber heads glued to the ends of a fiber tube. The primary winding consists of two layers of No. 20 B. & S. gauge, single silk-covered copper wire. Over this is wrapped a layer of waxed paper, upon which is wound the secondary winding, which consists of two No. 34 B. & S. gauge, single silk-covered wires wound on at the same time, so as to be parallel throughout their entire lengths. The resistance of this secondary coil is 70 ohms. Heavy wires *s* and *s'* are connected to the

FIG. 55.

fine-wire terminals of the secondary winding at points within the spool, and these are led through the heads of the spool in the ordinary manner. This is done as a precaution against breakage of the very fine wires in handling.

139. Varley Coils.—An innovation in the art of coil winding has lately been introduced by the Varley Duplex Magnet Company. Their method is, wherever possible, to wind with bare wire. In order to prevent the short-circuiting between the various convolutions, a silk thread is wound parallel with the bare wire throughout its length, so that the adjacent convolutions are always held a slight distance apart. Between the several layers of the winding are introduced thin layers of oiled paper. This winding is accomplished entirely by automatic machinery, and the coils produced are nearly perfect. The machines are run at a high speed, and at the proper intervals the layers of paper are introduced without stopping the machine or without the volition of the operator. This method, while being cheaper than the ordinary method, in which insulated wire is used, has also the additional advantage of making possible a given number of turns of a certain size of wire in a smaller space than can be obtained by the old method. Again, the convolutions are arranged with practically perfect uniformity, in decidedly sharp contrast to the results produced by the usual method, in which the wire is fed to the machine by hand.

140. The Design of Induction-Coils.—It is found in practice that the induction-coil best suited for one transmitter will not give the best results with another. It is therefore desirable to design a coil with reference to the particular make of transmitter with which it is to be used. Unfortunately, the complexities of the problem are such as to render its treatment from a mathematical standpoint, with the object in view of producing practical results, out of the question. The method usually employed, therefore, is one of comparison, a large number of coils of various proportions and resistances being tested with a view to finding out which will produce the best results. In choosing the proportions of the trial coils, the experience of others may be used as a guide within certain limits.

141. A convenient method, in case a somewhat extensive investigation is to be made, is to decide on a certain dimension and length of core, and then to wind perhaps 10 of them with primary coils, using different sizes of wire and with varying numbers of turns. Ten secondary coils may then be wound on thin spools, each one adapted to fit snugly over any one of the trial primary coils. Supposing that each of the primary coils and also of the secondary coils are numbered consecutively from 1 to 10; a certain primary, say No. 1, is chosen and tested with each of the 10 secondaries in succession. The combination producing the best result is noted. Primary coil No. 2 is then tested, using each of the secondaries in succession, and the best combination again noted. Similarly, the best combination between the various secondaries and each of the primaries may be determined. It now remains to choose between the 10 combinations of primary and secondary determined upon, and the method in this case may be the same as that already followed out. In this manner, by winding 10 different primaries and secondaries, a choice may be had from the equivalent of 100 induction-coils, thus making it possible to cover a wide range with a comparatively small outlay.

142. Differences Between Good Coils.—To illustrate the differences in the induction-coils that have been found to give the best results with different transmitters, the following table is given:

Transmitter.	Primary.	Secondary.	Length.
Blake	.48 ohm.	250 ohms.	2½ inches.
Western	.38 "	70 "	4 "
Solid-Back	.50 "	14 "	6 "

The resistance of the secondary used with the solid-back transmitter is surprisingly low, and demonstrates, perhaps, the extreme limit towards which the tendency in the construction of induction-coils has been in recent years. It is commonly supposed, particularly among the independent companies, that the higher the resistance of the secondary of an induction-coil, the better will be the result; and it is not uncommon to find contractors specifying 500-ohm and even 750-ohm coils. Such specifications, if adhered to, often prove decidedly detrimental to the service, for reasons which will be made more apparent later.

CALLING APPARATUS.

BATTERY CALLS.

143. So far, only that apparatus used in the actual transmission of speech has been considered. The telephone receiver is capable of making only a feeble sound, and it has therefore been found necessary to provide some means with each telephone for sending or receiving signals capable of being heard at a considerable distance from the instrument, whereby a party with whom another desires to converse may be brought to the instrument. Inasmuch as telephones are usually supplied with a battery for operating the local transmitter, it would appear at first sight most advantageous to use the energy from this battery for operating the call-receiving instrument at the opposite end of the line. This is, in fact, often done on comparatively short lines, but this method of signaling has certain limitations, which will be pointed out later

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VIBRATING BELLS.

144. Construction.—The bell used for battery-call work is usually of the type known as the vibrating or trembler bell, one form of which is shown in Fig. 56. The hammer of this bell is arranged so as to vibrate rapidly back and forth and to strike the gong at each vibration, thus producing a continuous succession of sounds. *D* and *D'* are two electromagnets having cores *F* and *F'* of soft iron secured to a soft-iron yoke piece *Y*. *G* is a soft-iron armature mounted by means of a flat spring *S* secured to a post *P*, so as to vibrate freely in front of the cores *F* and *F'*. The armature carries a hammer, as shown, adapted to strike the gong a sharp blow when the armature is pulled towards the magnet cores. If the circuit through the magnets passed from one terminal of the binding-post *T* through the coils directly to the other binding-post *T'*, then closing the circuit containing a suitable battery would cause the hammer to strike the gong a single blow. A succession of blows might be produced by rapidly making and breaking the circuit at the point from which the signal was being sent; but this would be an unsatisfactory method. Therefore, the armature of the bell is so arranged as to

FIG. 56.

make and break its own circuit by its vibration. In this way a rapid and continuous succession of strokes is produced as long as the terminals of the battery are connected to the two binding-posts *T* and *T'*. To bring about this result, the circuit between the binding-posts of the bell is made as follows: From the binding-post *T*, which is insulated from the frame of the bell, a wire leads to one terminal of the coils *D* and *D'*, which are connected together in series. A wire leads from the other terminal of *D'* to the metallic post *N* insulated from the metal framework and provided with a contact screw *M*. While the armature is at rest, a contact spring *X*, carried by the armature, rests against the contact screw *M*, thus carrying the circuit to the armature and the post *P*. This post *P* is connected with the frame of the bell, as is also the post *T'*, so that the circuit from *P* to *T'* is completed through the frame itself. When a current is sent through the coils, the armature will be drawn forwards, thus causing the hammer to strike the gong. This movement, however, will break the circuit by causing the spring *X* to move out of contact with the screw *M*. This interrupts the flow of current through the coils and therefore allows the armature to spring back, it being no longer attracted by the magnet cores. In doing this, contact is again made between the spring *X* and the screw *M*, thus completing the circuit, and again energizing the magnets, thus producing another stroke of the hammer. This process is repeated as long as the circuit is held closed at the sending station. The spring *X* is provided so that the circuit will not be broken as soon as the armature starts to move towards the cores. Its function is to prolong the time during which the circuit is closed, so as to allow the magnets to exert a pull on the armature until the hammer is almost in contact with the bell.

145. Design.—These bells are manufactured in almost numberless styles, many of which are of exceedingly poor design, from both mechanical and electrical standpoints. A good battery bell should be so well constructed that none of its parts are likely to work loose by virtue of the rapid and violent vibration of the hammer. The point of the screw *M* and also the surface on the spring *X* should be tipped with platinum, in order that the surface of the contacts may be kept clean, as platinum will not corrode under ordinary atmospheric conditions, and is, moreover, not affected much by the electric spark, which is sometimes very heavy between these contacts. Silver, being cheaper, is frequently used in place of platinum, and is superior to copper, brass, and iron. The screw *M* should be provided with a lock-nut, or with some other means of locking it securely in any position to which it has been adjusted. If this is not done, the vibration of the armature will cause the screw to gradually work back, until finally it reaches a point where the spring *X* will not make contact with it. This locking is sometimes accomplished by splitting the post *N*, so that the screw-threads in the two halves exert a combined action on the screw, due to the elasticity of the parts of the post.

146. Prevention of Sticking.—Means must be provided for preventing the armature from coming in actual contact with the poles of the electromagnet, as the residual magnetism would cause it to stick and not allow the spring *S* to move it back at once or at all. This may be done in a number of ways, one of which is to secure a thin strip of copper to the surface of the armature which would come in contact with the poles. Another way is to insert a small pin of brass or copper into the ends of the poles in such manner that they project slightly beyond the pole surfaces. Either of these methods should prevent actual contact between the iron surfaces, and therefore eliminate the tendency to stick. This tendency is particularly great where the magnets and armature are not of the best quality of soft annealed iron, because the harder iron retains its residual magnetism with more tenacity. In a first-class bell, these parts are made of the softest grade of wrought iron, so as to be more readily demagnetized when jarred by the striking of the armature against the cores.

147. Adjustment.—The adjustment of battery bells is a very simple matter, and usually the turning of the screw *M* until it occupies the desired position is all that is required. The best position may be determined by gradually turning it, while the circuit is closed, until the hammer vibrates in such a manner as to produce a succession of hard, sharp blows against the gong. If the screw *M* is too far back, the circuit will be opened before the armature has acquired sufficient momentum to carry the hammer forwards to the gong, or it may be so far back as not to allow the circuit to be completed at all. On the other hand, if the screw is too far forwards, the spring *X* will not be pulled away, and the circuit will not be broken at all, or else the break will occupy such a short space of time that the hammer will not be allowed to recede far enough to strike a proper blow on the gong. If the adjustment by means of the screw *M* does not produce the desired results, it may be that the armature *G* does not occupy a proper position with respect to the poles of the magnet. When the hammer rests against the gong, the distance between the armature and each of the pole-pieces should be approximately the same. This adjustment may, as a rule, be made by bending the spring *S* slightly, or by shifting the positions of the magnets themselves.

148. Sometimes the surface of the gong against which the hammer strikes does not occupy such a position as to allow the hammer to strike it at the proper moment. If the gong in Fig. 56 is too far to the right, the hammer will strike before the armature has moved far enough towards the pole-pieces to allow them to attain their maximum pull. If the gong is too far to the left, then the armature will strike the pole-pieces before the hammer strikes the gong; in either case a loss of efficiency will result. This may be remedied by bending the rod on which the hammer is mounted, but in many cases a better way is to turn or move the gong itself on its standard. They are usually somewhat eccentric, due to imperfections in their manufacture, and therefore by turning them, the surface against which the hammer strikes may be brought into the correct position.

149. Fig. 57 shows such a bell connected in circuit with a battery and push-button. By pushing the button, the circuit is closed at *c*, thus allowing the action already described

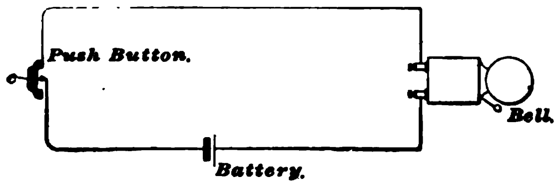


FIG. 57.

to take place. This circuit is such as would be used for an ordinary push-button call for almost any purpose. In order to prevent the running of separate wires for the telephone circuit and for the calling circuit, special arrangements of circuits are made, which will be described later in their proper place.

LIMITATIONS OF THE BATTERY CALL.

150. Except for very short lines, the system of calling by means of a vibrating bell—using the transmitter battery for producing the necessary current—has proved a failure. The vibrating bell is not a wonderfully sensitive instrument, and for operation over long lines, a considerable amount of battery power is required; it has therefore been found impracticable to successfully operate them without the use of a far greater number of cells than would be required for the mere operation of the transmitter. Moreover, the batteries are subject to a somewhat severe use in supplying current to the transmitters, because the transmitter circuit is usually of very low resistance, and may be left closed for a considerable time and at frequent intervals. Several attempts have been made to successfully operate bells by means of a current induced in the secondary winding of an induction-coil, by rapidly making and breaking the primary circuit in which was connected the transmitter bell. By this means almost any desired voltage may be obtained; but the current is correspondingly reduced, and to such an extent as not to be able to produce the desired effect on the bells.

151. Battery Call in Telephone Exchanges.—The remarks in the preceding articles concerning the poor working of the battery bell in telephone work must not be taken as applying to all means of calling using battery current. In some of the most improved telephone exchanges, the signal from the subscriber to the central office is given by means of current derived from a battery, and systems based upon this plan of operation are proving so successful that there is a probability of their almost universal adoption. In these, however, the signaling is not done by means of a bell, but by means of a sensitive annunciator, and the battery, instead of being located at the subscriber's station, is usually placed at the central office. These systems will be dealt with in full in subsequent Papers.

MAGNETO CALLING APPARATUS.

152. The deficiencies in the system of calling by means of the battery bell were recognized at a very early date in the art of telephony, and as a remedy, the magneto-generator and polarized call-bell were produced. The magneto-generator is, in fact, a very simple form of dynamo, capable of generating an alternating current of a moderately high voltage and with a sufficiently large current to accomplish the desired results. The polarized call-bell, or ringer, as it is now commonly termed, in order to respond to these currents, is of a peculiar construction, adapted to respond to much more feeble currents than the battery bells already described.

The magneto-generator and polarized bell are usually mounted in a single box, and have always been so closely associated with each other that it is customary to speak of the two, when mounted together, as a magneto-bell, or, more commonly, as a magneto.

THEORY OF THE MAGNETO-GENERATOR.

153. Law of Electromagnetic Induction.—The action of the magneto-generator depends directly upon the laws of electromagnetic induction, pointed out in *Principles of Electricity and Magnetism.* One way of stating this law is, that if the number of lines of force passing through a coil of wire is varied, an electromotive force will be set up in the coil, the intensity of which will depend upon the *rate* at which the lines are varied, and the direction of which will depend upon the *direction* of the lines and upon whether their *number* is being *increased* or *diminished.* One way of varying the number of lines through a coil has been pointed out in the case of the induction-coil, where a field of force is established by a current flowing in a primary coil, the lines of this field being caused to pass also through a secondary coil. Any changes in the strength of the current in the primary cause corresponding changes in the strength of this field, which, by the law just stated, produce electromotive forces in the secondary coil. Another way of changing the number of lines of force passing through a coil is to move an electromagnet or a permanent magnet in the vicinity of the coil. Still another way is to move the coil with respect to the magnet; and it is by this method that the magneto-generator is made to produce electromotive forces, and, therefore, when the circuit is closed, corresponding currents.

154. Induction in Revolving Loop.—In Fig. 58 is shown a closed loop of wire which may be revolved about a horizontal axis $x\,x$ within the field of a set of three permanent magnets N, S. The lines of force are indicated by the horizontal arrows, their direction being from the north pole to the south pole according to the usual conception of their flow. The rotation of the loop about the axis $x\,x$ in the direction of the curved arrow may be given by any suitable means.

When the loop is in its horizontal position, it will lie in a plane parallel to the lines of force, and therefore will include none of the lines. As it is turned into the position shown by the full lines, it will include more and more of the lines

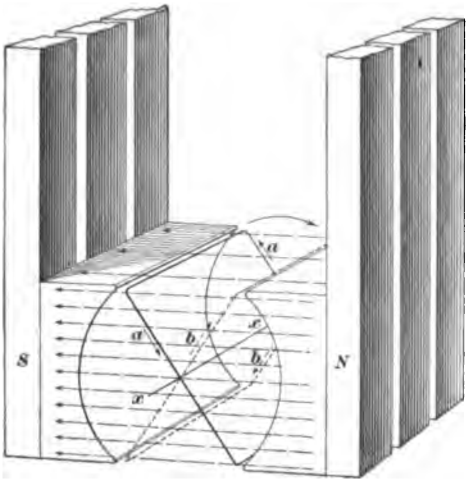


FIG. 58.

of force, and therefore will have an electromotive force and a corresponding current set up in it in the direction of the arrows *a*. When the coil reaches its vertical position, it will include all the lines of force, and from that point on the number of lines through the coil will be in the same direction, but will be decreasing. Therefore, the direction of the current through the coil will change after passing the vertical position, and the flow of current will then be indicated by the direction of the arrows *b*.

155. If the coil is revolving at a constant speed, the rate of change of the lines of force through the coil will be very slow as it approaches and recedes from its vertical position, being zero when the plane of the coil is at right angles to the direction of the lines of force, and therefore the induced electromotive force is here zero. As the coil approaches its horizontal position, the rate at which the number of lines through it is changing will increase, and the electromotive force will therefore correspondingly increase, although the actual number is more and more rapidly being reduced to zero. When the coil reaches its horizontal position, the electromotive force in it will be a maximum because the rate of change of the lines of force is a maximum, although the number threading through the coil is zero. At that point, the number of lines passing through the coil again begins to increase; this would produce a change in the direction of the electromotive force were it not for the fact that the direction of the lines through the coil relatively to the plane of the coil also changes. The electromotive force is therefore at a maximum at the horizontal position of the coil, because the rate of change of the lines through the coil at that point is a maximum. As the coil again approaches its vertical position, the rate of change becomes less and less, and as it reaches that position, no change takes place, and the electromotive force therefore becomes zero. From this point on to the starting-point, the number of lines decreases, therefore, again producing an electromotive force in the opposite direction, which becomes a maximum as the horizontal position is reached.

156. Graphical Representation of Generator Current.—The flow of the current to and fro in the coil may be represented by a sine curve, such as is shown in Figs. 3 or 5, the distances above or below the horizontal axis being made proportional to the instantaneous values of the current or the electromotive force, whichever the curve is considered to represent. Assuming the curve in Fig. 5 to be an electromotive-force curve, the point *A* upon it corresponds to the vertical position of the loop in Fig. 58. At this point no electromotive force is set up in the loop, and therefore the point *A* is on the horizontal axis of the curve. As the loop rotates on its axis, the electromotive force gradually increases until it lies in a horizontal plane, where the electromotive force is a maximum because the lines of force are then being cut by the loop at a maximum rate. This condition is represented by the point *B* on the curve where the ordinate representing the electromotive force is a maximum. From the horizontal position of the loop in Fig. 58, the electromotive force remains in the same direction, but decreases until the coil again reaches a vertical position, when it becomes zero; this is represented by the point *C* on the curve. At this point the direction of the electromotive force changes and the curve passes below the horizontal line, and during the next half revolution of the loop, while approaching the second horizontal position, the changes are of the same nature but in an opposite direction, the electromotive force reaching a maximum in this direction at the point D corresponding to the second horizontal position of the loop, and again decreasing to zero, as shown at E, when the loop is at the same vertical position from which it started.

A complete revolution of the coil, therefore, produces one complete cycle of changes in the electromotive force and in the current.

157. Construction of Armature.—Instead of having but a single turn of wire, as in the loop shown in Fig. 58, a coil consisting of a great number of turns is used in practice, so that the electromotive force generated in each turn may be added to that of all the others. Furthermore, in order that the greatest possible number of lines of

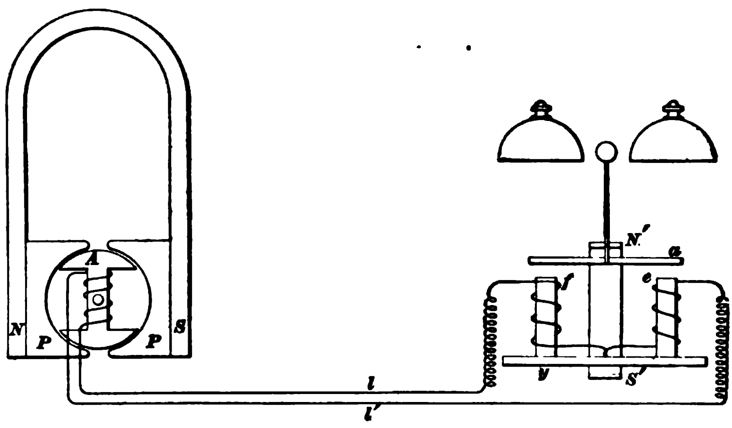


FIG. 59.

force may flow between the magnet poles and through the coil, the coil is wound upon a core of soft iron adapted to fit closely between curved polar extensions or pole-pieces of iron secured to the poles of the permanent magnets. Such a construction is shown diagrammatically in the left-hand portion of Fig. 59. In this, *A* represents the armature core of iron adapted to rotate within the space formed by the iron pole-pieces *P*, *P*, secured to the poles of the permanent magnet *N S*. Around the shank of the armature core, in a longitudinal groove provided for the purpose, the coil of insulated wire is wound. This coil entirely fills the space provided by this groove, although it is represented, for the sake of clearness, as consisting only of four turns, in Fig. 59.

THEORY OF THE POLARIZED BELL.

158. Construction.—The polarized bell, or ringer, is a device adapted to respond to the alternate currents set up by a magneto-generator. It is shown in diagram in the right-hand portion of Fig. 59, in which *e* and *f* are soft-iron cores connected by a yoke piece *y* of similar material. Around these cores are wrapped coils of insulated wire in opposite directions, as shown. The armature is also of soft iron, and is pivoted at its center so that its ends may be attracted or repelled by changes in the magnetism of the cores *e* and *f*. This armature carries a hammer adapted to strike alternately against two small gongs as it vibrates to and fro. *N' S'* is a permanent magnet so placed as to magnetically influence the cores *e* and *f* and the armature *a*. Thus, the armature *a* being near the pole *N'* of the permanent magnet, its middle will have south polarity and its ends north polarity; while the upper ends of the cores *e* and *f* will be of the opposite polarity, by virtue of the lines of force from the south pole *S'* passing through the yoke *y* to each of the cores *e* and *f*. We may thus consider that normally the upper extremities of the cores *e* and *f* are south poles, while both ends of the armature *a* are north poles. Under normal conditions, therefore, one end or the other of the armature *a* will be held in contact with one or the other of the poles *e*, *f*, according to which one happens to be the nearer.

159. Action of Currents in Either Direction.—If a current in one direction passes through the circuit of the coils, it will affect the cores *e* and *f* in opposite manners; that is, if it is of such a direction as to make the upper end of the core *f* a north pole, it will tend to make the upper end of the core *e* a south pole—this, by virtue of the fact that the current passes around the two cores in opposite directions. If the current is in the reverse direction, it would tend to make the upper end of the core *f* of negative or south polarity and the upper pole of *e* of positive or north polarity. Inasmuch as the upper ends of the cores *e* and *f* are both normally negatively polarized, a current in the former direction will tend to strengthen the pole *e* by adding to its negative polarity, while it will correspondingly weaken the pole *f* by neutralizing its negative polarity, because the current tends to make it positive. This will cause the armature *a* to be attracted by the pole *e*, and cause the hammer to strike the right-hand gong. The current in the opposite direction will strengthen the pole *f* by adding to its negative polarity, and will weaken the pole *e* by neutralizing its polarity by the positive polarity set up by the current. The armature will therefore be attracted by the core *f*, and the hammer will strike the left-hand gong.

160. Action of Alternating Currents.—It has been shown that the currents generated by the magneto-generator are alternating in character, flowing first in one direction and then in the other. It is obvious, therefore, that a positive impulse of current from the generator will, in flowing through the coils of the polarized bell, cause its armature to move in one direction, while a negative impulse of current will cause the armature to move in the opposite direction. Inasmuch as positive and negative impulses follow each other in rapid succession, the armature of the bell is caused to vibrate in unison with them, thus producing the well-known sound of the telephone bell.

TYPICAL MAGNETO-GENERATOR.

161. Construction.—In Fig. 60 is shown two views of a magneto-generator which may be considered as a typical telephone generator. The pole-pieces *P* are of cast iron, having the surfaces which face each other machined into cylindrical form. These pole-pieces are held in position by the sheet-brass end-plates *B*, secured to their ends by screws *b* passing through the end-plates themselves and into tapped holes *p* in the pole-pieces. The armature core is of cast iron, of a form shown in side and end elevation in Fig. 61. The shaft of the armature, which is cast as an integral part of the core, is turned in a lathe so as to form suitable bearing surfaces *a*, *a*, adapted to turn freely within the bearings in the end-plates *B*, Fig. 60. The cylindrical surface *c c* of the armature core is also turned, while on the same centers, to a diameter slightly less than the internal diameter of the cylindrical surface between the pole faces, so that the armature may rotate freely when in place.

162. The armature in generators of this type is usually wound with No. 36 wire to a resistance of about 600 ohms, the wire lying in the space formed between the pole cheeks on the core and the shaft. One end of the armature shaft is bored for the reception of a hard-rubber plug, into which is set a brass pin *Q* projecting beyond the end of the shaft. This pin is insulated from the body of the armature, but is in metallic contact with a second insulated pin *q* projecting through a hole bored in the side of the armature spindle and screw-threaded into the pin *Q*. This construction is clearly shown in the small detached cut in the left-hand portion of Fig. 61. To this pin *q* is attached one end of the wire forming the armature coil, while the other end is attached to a similar pin *q'* screwed directly into the metallic shaft. The pin *Q* therefore forms one terminal of the armature coil, while the shaft itself forms the other terminal. The winding is represented in Fig. 61 by a few turns of wire *w* instead of a large number of

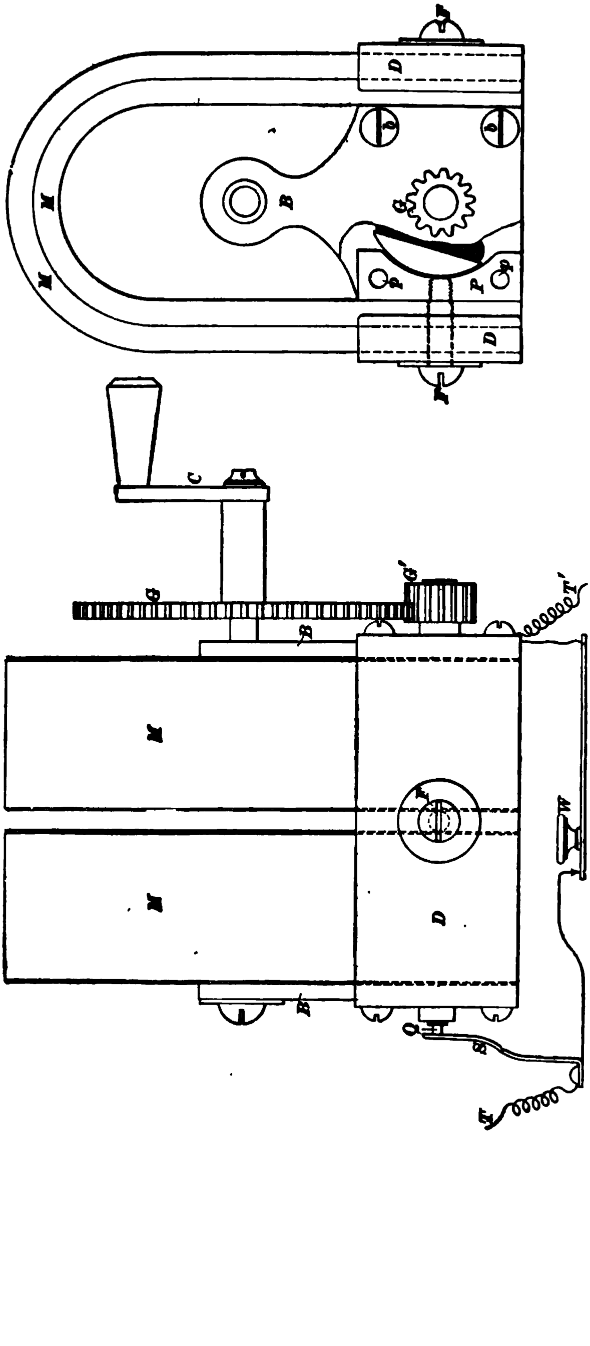
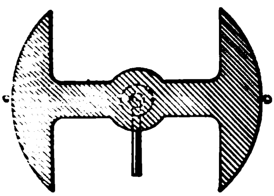


FIG 60.

turns, in order that the path from the pin q to pin q' may be readily traced.

163. A rapid rotary motion may be given to the armature by means of the crank *C*, Fig. 60, through the medium of



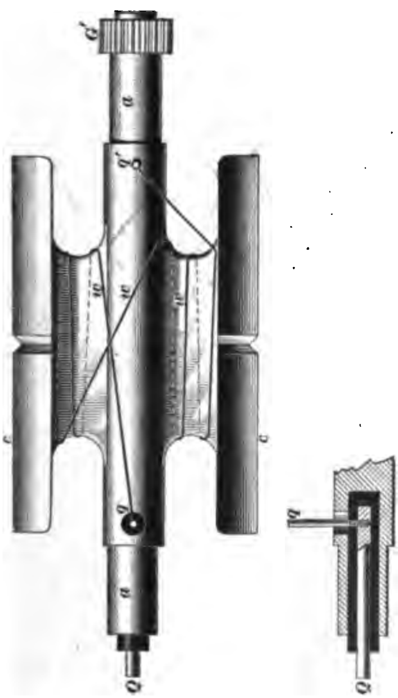


FIG. 61.

the large gear-wheel *G* mounted directly on the crank-shaft, which engages a pinion *G'* mounted directly on the armature shaft. The ratio of the number of teeth on the large gear-wheel to the number on the pinion is usually about 5, so that 1 revolution of the former produces about 5 revolutions of the armature. The crank-shaft is journaled in bearings formed in outward extensions of the end-plates *B* on each side of the machine.

The permanent magnets *M* are of horseshoe form, and four in number; they are clamped in position against the outer faces of the pole-pieces by the screws *F* passing through the clamping plates *D*, between the two pairs of magnets and into the pole-pieces *P*. These magnets are, of course, all arranged with their like poles together, so that the sum of their magnetic effects may be secured.

164. Connections With External Circuit.—In order that the currents generated by the rotation of the armature may be sent out over an external circuit for the ringing of bells or other purposes, one wire T' is attached to the frame of the machine, which is in constant electrical contact with the terminal of the armature winding that is secured directly to the shaft, the connection being through the end-plates B and the bearings of the armature. Another wire T forming the other terminal of the external circuit is attached to the spring S, which bears with considerable pressure against the end of the pin Q, which, as has been shown, is in electrical contact with the other terminal of the armature winding.

165. Generator Shunts.—It is found desirable, for reasons that will be made clearer later, to provide a path of low resistance around the armature coil at all times when the generator is not in actual use. The simplest way of accomplishing this is by means of a push-button W, which normally maintains a closed circuit between the two terminals T and T' leading from the generator. If the generator is operated without depressing the push-button, the current from the armature would flow through the short circuit between the two terminals and would not pass out over the external circuit at all. In order to provide against this, the button W should be depressed while the generator is operated, so as to remove the presence of the short circuit.

There are several reasons why it is desirable to have this shunt around the armature. It may save the armature coil from being burned out by heavy currents that come in over the line, due to lightning or other causes. This alone, however, would not warrant its use, and it is not the chief reason. This will be made clear when the circuits of complete telephone instruments are discussed.

166. Voltage of Generators.—The voltage given out by any magneto-generator depends on the strength of the magnetic field, on the number of turns of wire on the armature, on the speed of rotation of the armature, and to some extent on the relation between the cheeks of the armature and the pole-pieces. At the usual rate of turning by hand, the machine shown in Fig. 60 should generate an electromotive force of from 60 to 75 volts when wound for ordinary service.

TYPICAL POLARIZED BELL.

167. The usual form of polarized bell is shown in Fig. 62, in which *m*, *m* represent the electromagnets wound

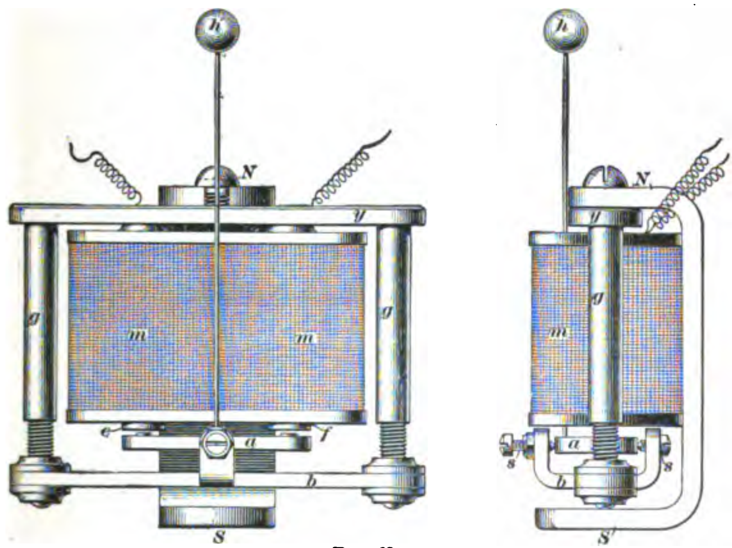


FIG. 62.

on the soft-iron cores *e*, *f*, secured at their upper ends to the yoke piece *y*. Brass rods *g*, *g*, riveted into the yoke piece *y*, support at their lower ends a bracket *b* having two projecting ears, in which the armature *a* is pivoted by means of pivot screws *s*, *s*. Carried by this armature is the hammer *h*, consisting of a slender brass rod and a ball for striking the gongs. Carried upon the yoke piece *y* is the permanent magnet *NS*, bent as shown. This magnet serves to give the yoke *y*, and consequently the core ends or pole-pieces *e* and *f*, a positive polarity, and the two ends of the armature *a* opposite the poles *e* and *f* negative polarity. Each end of the armature will therefore be attracted with about equal force by the two poles *e* and *f*, and the armature will adhere to the one to which it happens to be the nearer.

The coils are wound in opposite directions, so that a current traversing them in series will tend to make one of the poles positive and the other negative, or *vice versa*, according to its direction. The action of this bell will be clear from the explanation already given.

DETAILS OF GENERATOR CONSTRUCTION.

168. Magnets.—The size of bar used for making permanent magnets varies with different makes of magneto, but probably the following are the most common dimensions: $\frac{3}{8}$ by $\frac{3}{4}$ and $\frac{1}{4}$ by $1\frac{3}{4}$ inches. The steel for this purpose is subject to the same requirements as already pointed out in connection with the permanent magnets for receivers, but inasmuch as the cross-section of a bar is, in the case of generators, considerably larger, a somewhat higher carbon steel is frequently necessary. This is so because the larger cross-section of the bar will not allow it to cool so quickly, and therefore, if a very low carbon steel were chosen, it would not attain sufficient hardness for proper magnetization. The steel used by some manufacturers is of such a quality as to allow it to be bent cold in a suitable forming-machine; and where this is the case, it is not only cheaper but better to do so as an additional heating of the steel is thereby saved.

169. Tempering.—The manner of holding the bar to be tempered is shown in Fig. 63. *A* is a block placed

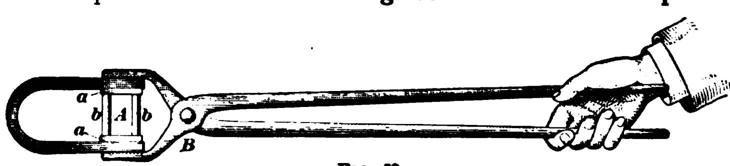


FIG. 63.

between the limbs of the horseshoe after it is heated to a cherry red for tempering, and against which the limbs are clamped by the jaws of the tongs *B* used for holding the bar to be tempered. The object of the block is to insure the setting of the steel in the proper form, as, without its use, the inside distance between the limbs would be either too great or too small after the bar was cold. In order that the cold water into which the bar is dipped may get at as much of the surface of the bar as possible, the block *A*, which is shown in detail in Fig. 64, is of skeleton form, being built up of two steel side-pieces *a*, *a*, held apart by shouldered rods *b*, *b*. The side-pieces *a*, *a* are drilled full of holes and made as thin as possible, in order to allow the water to come into contact with the steel as much as possible. For the same purpose, the jaws of the tongs are corrugated in such manner that the actual contact between them and the surface of the steel is very small. It is highly essential that the water shall be cold, and therefore it is necessary, where a large number of pieces are to be tempered, that it be constantly changing, as otherwise the repeated immersion of the hot bars would cause it to become too warm for efficient service.

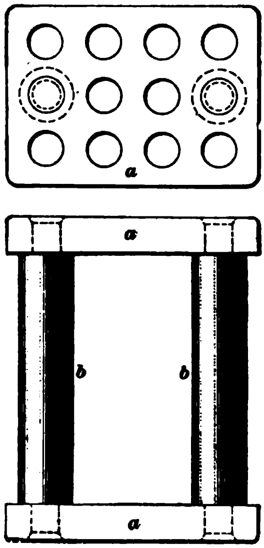


FIG. 64.

170. Inasmuch as any mechanical shock tends to lessen the permanent magnetism of a bar of steel, it is highly important that no such operations as grinding on an emery-wheel be performed on the bar after it is magnetized. It not infrequently happens that the magnetization is seriously impaired by makers grinding the surfaces of their magnets for the purposes of nickel-plating, or for other reasons, after they have been magnetized. All such operations, if performed at all, should be done before the bars are magnetized.

171. Armatures.—The most common form of armature core is that shown in Fig. 61, which is of cast iron. Armatures with such cores are capable of producing good results, provided the proper attention is given to the quality of iron used in the cores. Also, in casting, great care should be taken that only the softest grades of iron are used and that the castings should not become chilled in pouring. This latter condition is somewhat difficult to comply with, inasmuch as it is very hard to pour such small castings without chilling them in parts.

172. Laminated Cores.—A far better form of armature, following closely the principles that have been found of the greatest advantage in the construction of dynamo machines in general, is provided with a laminated core, that is, one built up of thin layers of soft sheet iron. Fig. 65 shows one of these armature cores, manufactured by the Holtzer-Cabot Company.

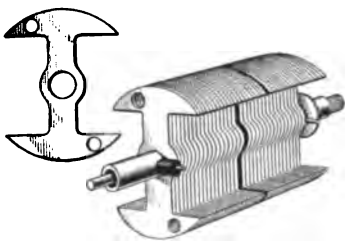


FIG. 65.

In this, the various layers of which the core is formed are stamped from a very soft quality of sheet iron, and are then placed upon a spindle of steel and clamped in position by nuts, as shown. The spindle on which the laminations are clamped forms the shaft of the armature, which is of the same general form when completed as the cast-iron armatures already described.

By this construction, not only is a far better grade of iron used in the armature core, but the formation of what are termed eddy currents is prevented. These eddy currents are currents set up in the core of an armature by the same inductive action that causes the currents to flow in the wire of the armature itself. If the core is of solid cast iron, it is evident that a complete circuit may be formed in it in the same direction as that formed by the wire in the winding. This circuit will be acted upon by the changes in the magnetic lines of force passing through it, in exactly the same manner as the circuit formed by the wire, and therefore currents of greater or less intensity flow through the core itself. These do no good, and, in fact, are harmful, inasmuch as the energy represented by them is wasted and inasmuch as their direction is always such as to oppose the flow of the legitimate currents in the armature winding itself. By laminating the core, these eddy currents are broken up, because the resistance between the various layers of the core is too high. This method of construction is absolutely essential in the building of larger-size dynamos, but its advantages seem to have been only recently appreciated in the construction of magneto-generators.

173. Winding.—Before winding an armature, it is necessary to properly insulate it, and this is usually done by wrapping upon it a layer of cotton-cloth, or paper, impregnated with shellac or an insulating varnish, so that it will adhere to the sides of the winding space. The armature is then secured in a winding-machine, usually on a threaded spindle, which engages a hole tapped in the side of the armature for this especial purpose. The wire is then fed on by hand, while the armature is rapidly rotated until the wire space is filled to the desired degree. Care must be taken that the space is not so full that the outside layers of wire are protruding beyond the cheeks of the core, as this would cause the wire to rub against the pole-pieces of the generator in turning and soon cause a break in the circuit. After winding, one end of the coil is fastened to the metallic portion of the core itself, usually, by a brass pin screw, threaded directly into the spindle, and the other end is fastened to the pin *q* (Fig. 61), which is insulated from the core itself, but in metallic contact with the pin *Q* projecting from the end of the spindle. By this construction, the armature winding terminates on one side in the pin *Q*, and on the other side in the armature core, and therefore in the frame of the generator, with which the core is in metallic contact through the shaft and bearings.

174. The size of wire and number of turns upon an armature varies according to the use to which the generator is to be put. For ordinary exchange service, however, the armature is usually wound with No. 36 B. & S., single silk-covered copper wire to a resistance of between 500 and 600 ohms. This is the usual winding for what is known as a 10,000-ohm generator, the significance of which term will be explained later.

175. Pole-Pieces.—The material of which the pole-pieces are made is usually cast iron, although in the many recent types of generators each pole-piece is stamped in one piece from a good quality of soft sheet iron. The advantages to be obtained by using a fine quality of soft iron in the pole-pieces are not so great as in the case of the armature core. One reason for this is that the flow of magnetic lines of force through the pole-pieces is always in the same direction, while in the armature, the direction of the flow is changed twice during every revolution. Inasmuch as a good quality of iron permits these changes of direction through it with a minimum loss, it follows that it is very essential to use the finest quality of iron in all parts subject to rapid changes in magnetization, while it is not of such great importance, although desirable, in parts where the magnetization is nearly constant.

The use of cast iron for pole-pieces enables a very accurate fitting of the pole-pieces to the armature itself, for the chamber in which the armature turns may be readily and accurately bored out to the required diameter. This degree of accuracy is somewhat lessened where the pole-pieces are stamped from sheet iron, as it has been proved impracticable to obtain as close a fit as where the interior of the pole faces were bored after having been firmly secured together in place. From this it will be seen that the air-gap between the armature core and the pole-pieces is necessarily larger in the case of the stamped sheet-iron pole-pieces than where the pole-pieces are of cast iron; and this feature alone will probably offset any advantages derived from the better quality of iron used. Still another objection to the use of sheet-iron pole-pieces is found in the fact that with ordinary construction it is impossible to obtain as good a magnetic joint between the pole-pieces and the inner surfaces of the bar magnets as where cast iron is used.

176. The ideal construction, where stamped pole-pieces are used, would be to conform the surfaces of the magnets themselves to the curved portions of the pole-pieces, so that there would be a large area of contact between them. This point will be dealt with at greater length later.

In a good magneto-generator, constructed with cast-iron pole-pieces properly turned and adjusted, it is practicable to have an air-gap of less than $\frac{1}{64}$ of an inch. It is possible to obtain a much smaller air-gap than this and still allow a free rotation of the armature, but this is likely to produce friction between the armature and the pole-pieces after the bearings become somewhat worn from long use.

177. Bearings.—The bearings for the armature are always subject to a greater amount of work than those for the crank-shaft, because of the fact that the armature usually rotates about five times as fast as the crank. In many of the cheaper generators, the end-plates, which form bearings for both the armature and crank-shaft, are stamped from sheet brass varying in thickness from $\frac{1}{16}$ to $\frac{1}{8}$ of an inch. The bearings are formed in these merely by reaming out the holes to the required size. This gives a very small bearing surface, and as a result the wear is excessive and the generator soon rendered inoperative, either by the striking of the armature cheeks against the pole-pieces or by the failure of the gear teeth to mesh properly. Where the greater thickness mentioned, that is, $\frac{1}{8}$ of an inch, is used, however, the generators frequently wear very well, provided the bearings are properly centered.

A better way, although a more expensive one, of making the bearings, is to insert a bushing of brass into the stamped end-plate, the bushing afterwards being reamed out to form the proper bearing surface. This method, or that hereinafter illustrated, in which the end-plates are formed of castings made of sufficient thickness to insure proper bearing surface, are now used in all the best forms of generators.

178. Driving.—The usual form of driving mechanism used in generators consists of a large gear-wheel mounted on the crank-shaft, meshing with a comparatively small pinion mounted directly on the armature shaft. One of the most common faults found in generators is due to the fact that the large gear-wheel is cut from very thin sheet brass, and even though it properly engages the pinion, after a short time wears a rut in it, due to the small area of contact between the teeth and the fact that the teeth on the small pinion make a rubbing contact about five times as often as do the teeth on the larger gear. It has been quite common to make the large gears only $\frac{1}{16}$ of an inch thick, and many are still constructed in this way; they should be carefully avoided in purchasing. As a remedy against this undue wear between the gears, the thickness of the large gear has been in many cases increased; and they are often now made with a tooth face $\frac{1}{4}$ of an inch wide.

The chain drive has been attempted, but, until recently, without success; this failure has been largely due to the use of improper design and materials. There is now, however, one form of chain-driven generator on the market which is giving excellent service, and which will be described in detail in its proper place.

179. Form of Current Wave. — The form of wave approaching most nearly that shown in Fig. 5, that is, the sine wave, has been found best suited for signaling over long lines. This, as we have seen, is the curve of the current generated by a coil of wire revolving at a uniform rate in a uniform field of force. In the magneto-generator, this form of wave is rarely ever attained, as the relation between the pole faces and the cheeks of the armature core does not give a uniform field of force, and so serves to modify this form of wave to a considerable extent. As has been already pointed out, when the center of the armature faces are opposite the center of the pole faces, the current is changing in direction and is therefore passing through zero. At right angles to this position, the current is a maximum. Were it not for the iron of the armature core, the changes in passing from the former position to the latter would be gradual, and the current curve would be approximately that of a simple harmonic wave.

180. Core Cheeks Too Narrow.—If the cheeks of the armature core are not wide enough to fill the gap between the pole faces when the plane of the armature coil is horizontal, the curve will assume the form shown in (*a*) of Fig. 66, that is, it will have two distinct humps in every half cycle. These humps may be readily accounted for. During the time while the cheek of the armature core is passing the pole-piece, there is but little change in the number of lines of force passing through the armature core, and the current therefore passes through zero as the armature passes through the position where the plane of the coil is vertical. As the corner of the armature cheek recedes from the pole-piece, however, there is a distinct rise in electromotive force and current, owing to the fact that the number of lines passing through the armature are rapidly decreasing. This causes the first hump in each half cycle of the curve (*a*). Almost immediately afterwards, the leading corners of the armature core approach the opposite pole corners, thus causing a great increase in the flow of lines through the core in the opposite direction. This forms the second hump in each half cycle of the curve.

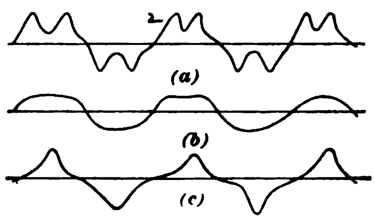


FIG. 66.

181. Core Cheeks Too Wide.—On the contrary, where the core cheeks are so wide that they overlap the intervals between the pole-pieces, the curve form will be flattened, as shown in (*b*) in Fig. 66. This is caused by the fact that the changes in the number of lines passing through the armature coil is always gradual. When the armature is in its vertical position, with the two core cheeks bridging across the intervals between the pole faces, a good path is formed for the lines of force through the cheeks without passing through the shank of the core. As the armature rotates, this condition is gradually changed, until the armature is in the position where the plane of the coil is vertical, when all the lines will pass through the armature coil.

182. Proper Width of Core Cheeks.—The best relation between the width of the core cheeks and the distance between the pole-pieces is such that each should occupy just 90° of the circumference of the cylindrical space in which the armature rotates, in other words, when the core cheeks will just fill the space between the pole-pieces when the armature coil is horizontal, and will just fill the cylindrical portions of the pole-pieces when the armature coil is vertical. With this construction, the current curve corresponds very closely to that shown at (*c*) in Fig. 66, which, it is true, is not a very close approximation to a simple harmonic curve, but probably the nearest approach that can be obtained in practice with the ordinary form of magneto-generator.

DETAILS OF POLARIZED BELL CONSTRUCTION.

183. Electromagnets.—The cores of the electromagnets in polarized bells should be of the best quality of soft iron obtainable. An imported iron from Sweden or Norway is used for these parts in the bells of the best manufacture. A good way of testing the quality of a piece of iron for a ringer core is to stroke it across the poles of a powerful electromagnet in exactly the same manner as if it were a bar of steel which it was desired to magnetize. If the iron is of suitable quality for the purpose, it will retain practically no magnetism, and a good test of this is to dip one of its ends in iron filings. If the core is of ordinary iron, a large number of filings will adhere to it, while if it is of the best grade of Swedish or Norway iron, properly annealed, very few, or none, of the filings will cling to it. In no place in a telephone instrument does the quality of iron play a more important part than in the ringer-magnet cores; for they are placed in a weak field of force, due to the proximity of a permanent magnet, and the strength of this field must be rapidly altered by the alternating currents from a distant generator. If the cores are hard, a current in one direction will set up magnetism in them, which it will be difficult for a succeeding current in the opposite direction to overcome; and inasmuch as impulses alternately opposite in direction follow each other at a high rate of speed, each impulse will find difficulty in overcoming the effects of the one before it. With three revolutions of the hand per second, there will be about fifteen periods per second.

184. The heads, forming with the cores the spools on which the coils are wound, are usually of fiber pressed into position upon the cores and secured thereto by friction only. Before winding, the core is carefully insulated by a layer of oiled paper. The wire used for winding the coils is usually single silk insulated and of a size suitable for the conditions under which the bell is to be used. The ordinary polarized bell-magnets for use with the common form of telephones is wound with No. 31 B. & S. gauge copper wire, each spool having a resistance of from 50 to 60 ohms, thus giving the two spools, when placed in series, a joint resistance of from 100 to 120 ohms. This figure is varied between wide limits to meet different conditions.

185. Frame.—The frame of the ringer upon which the electromagnets of the armature is mounted assumes widely different forms in different styles of instrument, and frequently includes the permanent magnet and the yoke piece. The yoke piece completing the magnetic circuit between the rear ends of the two cores should be of the same quality of iron as the cores themselves. In some ringers, this yoke assumes the form of a heavy cast-iron U-shaped bar, which supports the two coils at opposite ends. This is very detrimental to the efficient action of the ringer, as the yoke frequently becomes polarized in one direction or the other, thus causing the armature to stick to such an extent that it can not be freed by the feeble impulses of current coming in over a long line from the generator at another station.

The same remarks apply to the armature of the bell which carries the striker or hammer. In general, it may be said that all portions of the structure of the ringer which form a part of the magnetic circuit should be of the finest grade of soft iron procurable, with the exception of the permanent magnet, which, of course, should be made of hardened steel, conforming to the same requirements as the steel for the generator magnets.

186. Adjustment.—A ringer should be adjustable in several respects, the principal one of which, however, is the adjustment between the relative positions of the bell hammer and the gongs between which it plays. The best way of accomplishing this is by providing for a lateral movement of the supports upon which the gongs are mounted. Another respect in which a ringer frequently needs adjustment is as to the distance between the armature and the cores. This is usually accomplished by means of adjustment screws, as shown in Fig. 62.

DIRECT-CURRENT MAGNETOS.

187. It is sometimes desirable, in the operation of special systems of calling, to provide a generator that will send out impulses of current in the same direction, instead of in alternately opposite directions, as in the usual form. For bringing about this result, a commutator consisting of two segments *a* and *b*, Fig. 67, is mounted upon the armature shaft. These two segments are insulated from each other and from the core of the armature, and to them are secured the two ends of the armature winding. At diametrically opposite sides of the commutator rest two brushes, as in the ordinary dynamo, these two brushes forming the terminals of the generator. If these brushes are made to bear upon the commutator at such points that when the brushes pass the dividing line between the two segments the current at that instant is just changing its direction, then the impulses sent out over the two brushes will all be in the same direction; for just as the change in direction in the current is taking

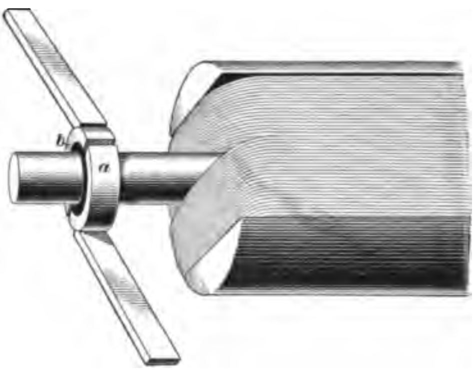


FIG. 67.

place within the armature winding, the connection through the brushes is reversed, and the two reversals taking place

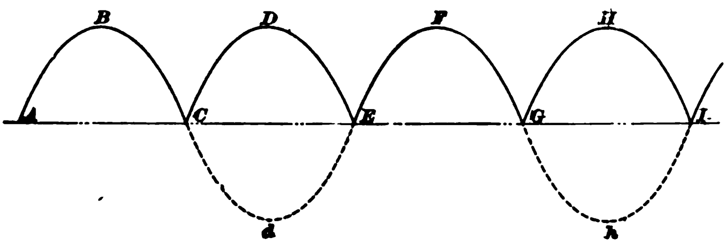


FIG. 68.

at the same time serve to keep the current in the same direction. The current is therefore pulsatory, and of the form shown by the full line *A B C D E F G H I* in Fig. 68.

THE GENERATOR SHUNT.

188. A very important adjunct to the magneto-generator is its shunt. It is desirable, as has been stated, that the resistance of the armature shall be removed from the circuit under normal conditions by having a path of practically no resistance closed around it. It is necessary that this low-resistance path, or shunt, be broken while the generator is in operation, as otherwise the current set up in the generator armature would pass from one terminal of the armature, through the shunt, and back to the other terminal of the armature, without passing through the external circuit at all. The breaking of the shunt may be accomplished by means of a push-button, as illustrated in Fig. 60 and described in Art. **165**; but it is a decided disadvantage to add to the number of operations that the user of a telephone must voluntarily perform, and therefore it is far better to provide some means whereby the shunt will be broken automatically by the turning of the crank. This is accomplished in a variety of ways, and a different kind of shunt is usually provided with each commercial type of generator. These will be described in connection with the generators to which they belong. All operate, however, to accomplish substantially the same electrical results as the push-button shown in Fig. 60.

COMMERCIAL FORMS OF CALLING APPARATUS.

WESTERN TELEPHONE CONSTRUCTION COMPANY'S MAGNETO.

189. Generator.—The form of magneto-generator recently adopted by the Western Telephone Construction Company for long-line work is shown in Fig. 69, in which *M*, *M*, *M* are the permanent magnets, bent from steel, having a cross-sectional area $\frac{3}{8} \times \frac{7}{8}$ inch. Before putting on the magnets, the pole-pieces between which the armature revolves are firmly riveted together, at a suitable distance apart, by means of shouldered brass rods. The two pole-pieces so fastened together are then placed in a boring-machine and the cylindrical space in which the armature is to turn carefully bored out. The armature, which is of somewhat greater diameter than in the ordinary form of generator, is then put in place, it being journaled in the end-plates *B*, *B* of cast brass, which are secured to the ends of the pole-pieces by screws, as shown. Vertical extensions, a

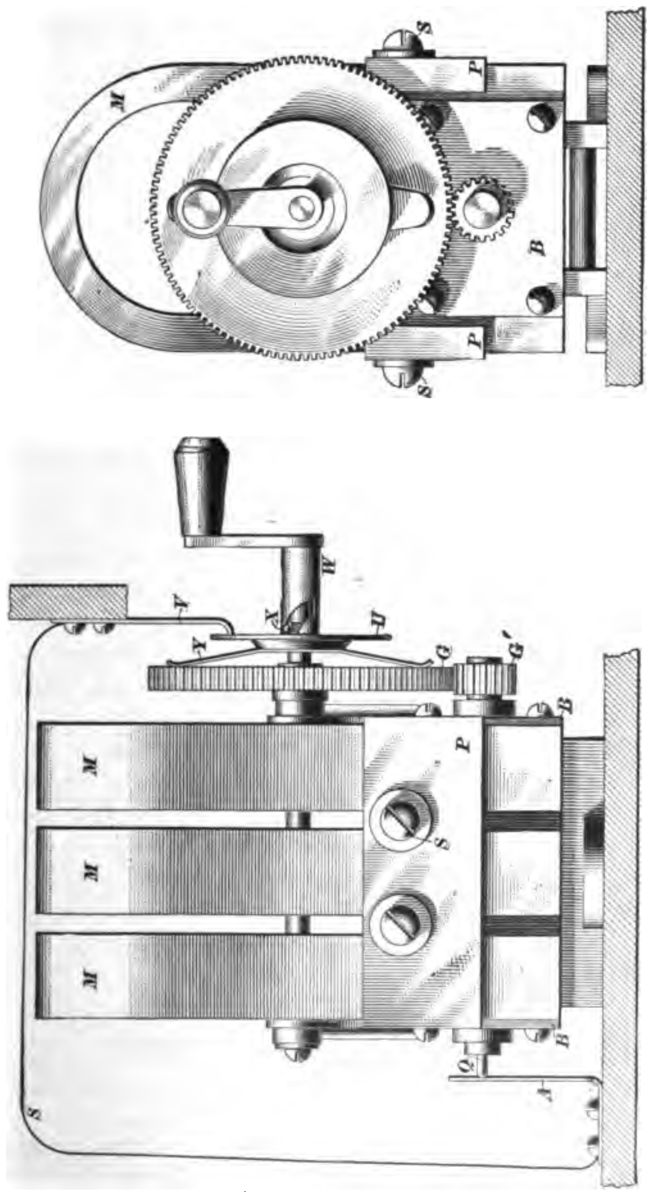


FIG. 69.

part of the end-plates *B*, form journals for the crank-shaft. The magnets are clamped into position on the pole-pieces by screws *S*, *S* passing through washers and clamping plates *P*, *P*, and then between the magnets, into the pole-pieces. Both the large gear *G* and the pinion *G'* are cut from cast-brass blanks, the width of the large-gear face being about $\frac{3}{16}$ inch.

190. Generator Shunt.—The automatic shunt of this generator is quite unique in design and accomplishes its purpose with satisfaction. The plate or collar *U* carried on the crank-shaft is of brass and is normally pressed towards the right by means of the spring *Y* which bears against the large gear-wheel. This plate *U* is therefore normally pressed against the spring *V*, secured to the inside of the generator box, this spring being connected by the shunt wire *S* to the spring *A* which rests against the armature pin *Q*. As the pin *Q* forms one terminal of the armature winding and the frame of the generator the other terminal, the wire *S* forms a short circuit around the armature, which is only broken when the collar *U* breaks contact with the spring *V*. This happens when the crank of the generator is operated, for the slotted sleeve *W* to which the handle is fastened and which is loosely mounted on the shaft, is automatically pressed towards the generator by means of the pin *X* riding on the inclined sides of the slot in the sleeve. This presses the collar *U* away from the spring *V* before the generator starts to turn, and therefore the shunt is never present while the generator is being operated. As soon as the hand is removed from the crank, the spring *Y* presses the collar *U* again into contact with the spring *V*, thus reestablishing the short circuit.

THE WILLIAMS MAGNETO-BELL.

191. Generator.—One of the latest generators placed upon the market is that of the Williams Electric Company, shown in Figs. 70 and 71, the latter figure having the permanent magnets removed for showing the interior parts. This generator is interesting on account of the several radically novel features it embraces. The end-plates *A* containing

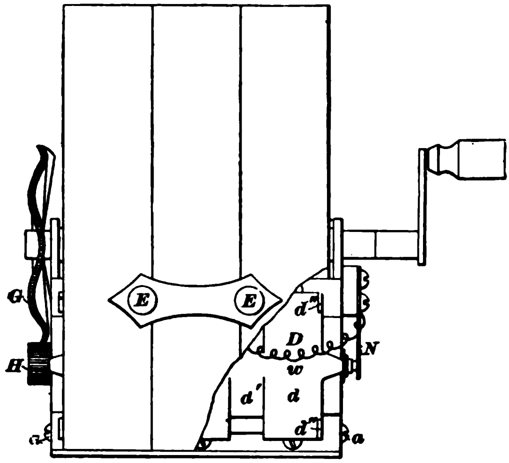


FIG. 70.

the bearings for the armature and crank-shaft are stamped from brass and are secured to distance-blocks, not shown,

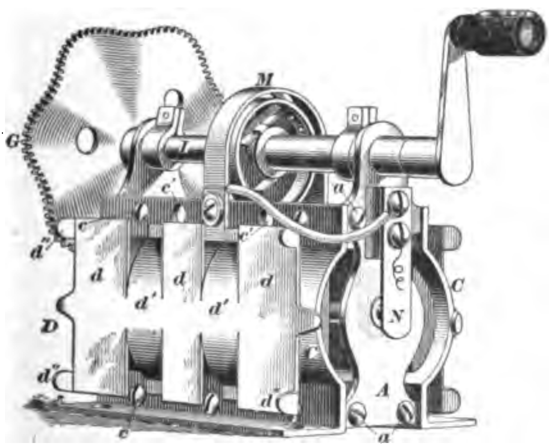


FIG. 71.

by machine-screws *a*, as shown. To these distance-blocks are also secured the pole-pieces *C* by means of the machine-screws *c*. The pole-pieces are stamped from a fine quality of soft iron and accurately formed, so that the space within which the armature revolves is very nearly cylindrical, and thus allows the free rotation of the armature with but a comparatively small air-gap. In order to obtain a more perfect path for the magnetic lines between the pole-pieces and the faces of the permanent magnets, the contact plates *D*, having three flat portions *d*, *d*, *d*, adapted to press outwardly against the permanent magnets, and two portions d', d', bent inwardly so as to correspond with the outside curvature of the pole-pieces, are provided; thus, by means of this contact plate *D*, a uniform distribution of magnetic lines is attained around the entire cylindrical surface of the pole-piece. Four lugs d'' are bent at right angles from the corners of the plate *D* to help hold the permanent magnets in their proper position. The magnets are further secured by the bolts *E*, *E* passing through them and through the holes c' in the pole-pieces *C*. These bolts are secured on the rear side of the generator, and are left of sufficient length to pass entirely through the bottom of the generator box, for the purpose of securing the generator in its place within the box.

192. Driving-Gear.—The most novel feature in connection with this generator, however, is the arrangement of the driving-gear. The large gear-wheel is radially corrugated, as shown, so as to distribute its wear uniformly over the pinion *H*, with which its teeth are meshed. Inasmuch as the gear-wheel *G* is about five times the diameter of the pinion *H*, the width of the pinion is made a corresponding number of times greater than the width of the gear, the object being to make the actual area of the surfaces on each of the two equal. In this way the wear is equally distributed between the teeth of the two wheels, instead of having a maximum amount of wear on the pinion, as is usually the case. In order to prevent the teeth of the large gear from wearing a rut in the surface of the pinion, the ratio between the number of teeth on the two is made an uneven number.

There are 27 teeth on the pinion and 134 teeth on the large gear, thus making the ratio slightly less than 5, and assuring the fact that any tooth on the pinion will come in contact with the same tooth on the large gear only once in every 134 revolutions.

The driving mechanism on this generator is mounted on the left-hand side instead of the right, as is the usual custom, the object being to prevent the uneven strain on the crank-shaft, due to turning the crank, from producing any effect on the gear teeth.

193. Automatic Shunt. — The shunt used on the Williams generator is of no less unique construction than the generator itself, and is shown in Fig. 72. This shunt is mounted as is shown in Fig. 71. *I* is the crank-shaft on which the large gear-wheel is mounted, and *J* is the crank tube embracing the crank-shaft and to which the crank itself is rigidly secured. *j* is a dog secured rigidly to the crank tube *J* and having two lugs *j'* adapted to engage with the flanges *k* upon the two pivoted pawls *K*. These pawls are pivoted upon a disk *L* mounted rigidly on the crank-shaft *I*, and are normally pressed outwardly by the small springs *k'*. *M* is an insulated metallic band, arched over the shunt mechanism and secured to, but insulated from, the pole-pieces *C*, as shown in Fig. 71. One or both of the pawls *K* is therefore normally held in metallic engagement with this band, and since the latter is connected by a wire *w* with the insulated spring *N* (Figs. 70 and 71) forming the spindle terminal of the generator, it forms a part of the short circuit around the armature coil. This short circuit may be traced from the terminal of the armature coil in connection with the frame of the machine, through the bearings to the crank-shaft and collar *L*, thence through the pawls *K* to the insulated metallic strip *M*, and thence by wire *w* to the spring *N*, forming the other terminal of the armature coil.

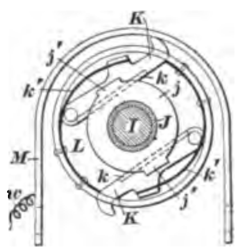


FIG. 72.

By turning the crank, the driving dog *j*, in following its circular path, presses upon and pulls inwardly the pawls *K*, disengaging them from connection with the metallic band *M*, and thus breaking the shunt around the armature.

194. The Williams Ringer.—The ringer forming the companion piece to the generator just described is entirely unlike anything heretofore put upon the market. It is shown in Fig. 73, in which *O* is a permanent magnet, so magnetized as to have one of its poles at its center *N*, the two ends together forming the other pole. Thus, if the center of the permanent magnet *N* is of north polarity, the two terminals *S*, *S* will be of south polarity. The coil consists of a single spool having a soft-iron bar for a core, riveted to the two heads *P* and *P'* of very soft sheet iron. These two heads are secured to the inner faces of the ends of the permanent magnet by means of properly bent lugs *p* and the screws *o*. The armature *Q* is pivoted at its center within a yoke piece *R* adjustably mounted in a bushing *T* secured to the center of the permanent magnet. The distance between the ends of the armature and the pole-pieces *P* and *P'* may be adjusted by sliding the rod supporting the yoke piece within the bushing, it being clamped in place by the set-screw *t*.

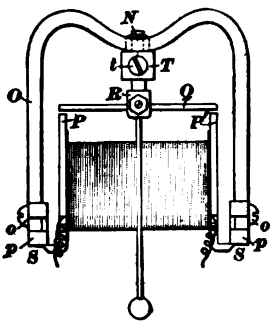


FIG. 73.

195. Magnetic Circuit.—The magnetic circuit of this ringer is illustrated in Fig. 74 by means of the iron filings which are held in the positions of greatest magnetic density. In this figure, the armature is removed, and it is seen that the greatest amount of lines of force are present at the point where the armature would be if in place. The flow of magnetic lines through the frame of this bell is from the center point *N* of the U-shaped magnet to the center of the armature, where it divides, half passing in one way through the armature to the pole-piece *P'* and half passing in the opposite direction to the pole-piece *P*; thence the flow continues through each pole-piece to the extremities *S*, *S* of the permanent magnet, and back to the center point. It will be seen that the core of the coil forms no part of this circuit, because both of its ends are of the same polarity. When the single coil is traversed by a current in one direction, the core is magnetized, and the return path of its magnetic circuit is through the soft-iron armature *Q*.

FIG. 74.

Under normal conditions, the ends of the armature *Q* are attracted with equal force by the pole-pieces, and the armature will therefore stick to either one or the other, according to which it happens to be nearest. If the current through the coil is of such direction as to tend to impart a north polarity to the pole *P'* and a south polarity to the pole *P*, then the pole *P'* will be weakened and the pole *P* strengthened, so that the armature will be attracted by the latter. Upon reversals of the current, the armature is drawn in the opposite direction. This ringer is well designed both mechanically and electrically, its mechanical advantage being its extreme simplicity and the fact that the working parts of the ringer are enclosed within the heavy steel magnet which affords them protection against mechanical injury. The electrical advantage is the fact that no lines of force pass normally through the core, which is therefore in a condition to be most readily affected by the magnetizing force of the coil.

THE WILLIAMS-ABBOTT RINGER.

196. This ringer, which is shown in Fig. 75, is the prototype of the ringer just described, and was the first one to use a **U**-shaped permanent magnet of the so-called tripolar type (the center being counted as one pole, and the two ends, although of like polarity, as the other two). In this, the permanent magnet *M* has its center point *N* of north polarity and its two ends *S*, *S* of south polarity. *A* is a yoke piece stamped from soft sheet iron, with bent-up portions having lugs *a* for securing it to the extremities of the permanent magnet. At intermediate portions on this yoke are secured the cores *P* and *P′*, upon which the two coils are wound. The armature *Q* is mounted in exactly the same manner as in the Williams bell, so as to play in front of these poles.

FIG. 75.

This ringer is remarkably efficient, and possesses the same mechanical advantages in the protection of the working parts by the permanent magnet as the Williams.

THE HOLTZER-CABOT GENERATOR.

197. Construction.—The Holtzer-Cabot generator, shown in Fig. 76, successfully embodies the chain-driving mechanism already referred to. In this generator, the pole-pieces *P*, *P* are of cast iron accurately bored out to form the armature chamber. The pole-pieces are secured to end-plates *A* and *B* by means of the screws *p*. These end-plates have on their inner surfaces shoulders corresponding in curvature to the bore of the pole-pieces, so that the inner surfaces of the latter when resting against these shoulders are accurately centered. The armature is that already illustrated in Fig. 65, being laminated and therefore capable of being constructed of the finest quality of iron. The magnets are clamped in place by short bolts *F* passing between them and into threaded holes in upwardly projecting parts of the pole-pieces. Upon an upright standard from the end-plate *B* is mounted, by means of the bolts *b*, *b*, the crank bearing C, in which the crank-shaft carrying the large gear-wheel rotates. The large and small gears are connected by means of a driving chain of steel links passing over both. The bearing C of the crank-shaft may be adjusted, in order to tighten or loosen the chain, by means of the slotted holes

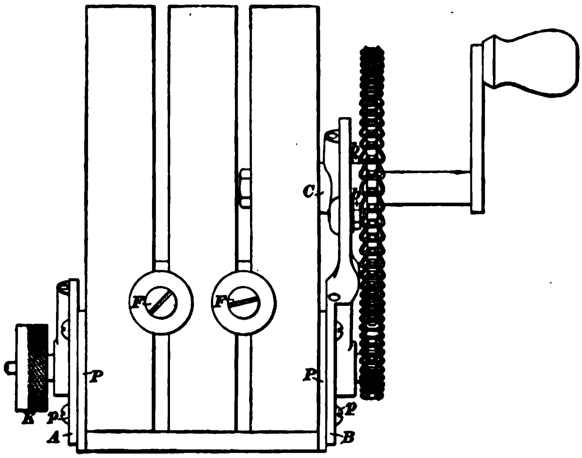


FIG. 76.

through which the bolts b pass. This method of driving secures a very smooth-running generator, and where the chain is constructed of such material that it will not stretch, and properly fitted to the gear-wheels, proves satisfactory in all respects. This generator is also made with gear-wheels in place of the chain.

198. Automatic Shunt.—The shunt K on this generator is of the simplest possible construction, and, moreover, is perfectly reliable. It is shown in detail in Fig. 77. In this, P is the contact pin projecting from the end of the armature shaft, with which one end of the armature coil is

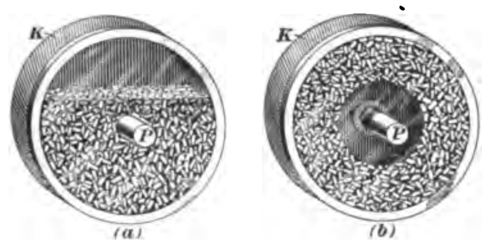


FIG. 77.

connected. *K* is a cup of thin brass, secured directly to the armature shaft, and therefore in metallic connection with the other terminal of the armature winding. *G* represents a mass of small metallic particles, formed by clipping No. 20 brass wire into very short lengths. These particles occupy about two-thirds of the space in the chamber within the cup *K*, and are held in place by a mica washer, through which the pin *P* projects. While at rest, as shown at (*a*), a short circuit is formed around the terminals of the armature by means of the metallic particles which electrically connect the pin *P* and the cup *K*. As soon, however, as the armature is rotated, centrifugal force causes the particles to fly towards the outer portions of the chamber, as shown at (*b*), leaving the portion immediately surrounding the pin *P* entirely empty. This opens the short circuit between the pin *P* and the cup *K*, and therefore breaks the shunt around the armature and allows the current to pass to line.

CAST IRON IN RINGER FRAMES.

199. Several forms of ringers that have been used to quite a large extent by the independent telephone companies have their frames made wholly or in part of cast iron. The great objection to bells wherein a large quantity of cast iron forms a part of the magnetic circuit is that the iron becomes strongly polarized by the currents traversing the coils, so that it is with difficulty that the magnetism set up by a current in one direction is destroyed by the current in the opposite direction. This point has already been referred to in the design of ringers. To this objection may be added a still greater one—that in the manufacture of these ringers but little attempt has been made in many cases to use a proper grade of iron in the cast-iron yoke or in the pole-pieces or the armature, and therefore the armature often becomes more strongly set towards one pole than towards the other, due to the polarization of the cast-iron yoke. This ringer is capable of giving only fair results when properly made, but when to its faulty design is added the defects due to poor material and workmanship, the result is poor indeed.

MISCELLANEOUS TYPES OF AUTOMATIC SHUNTS.

200. Western Electric Shunt.—Several forms of automatic shunt have already been described in connection with the various generators to which they belong. There are several others, however, which merit attention. The one

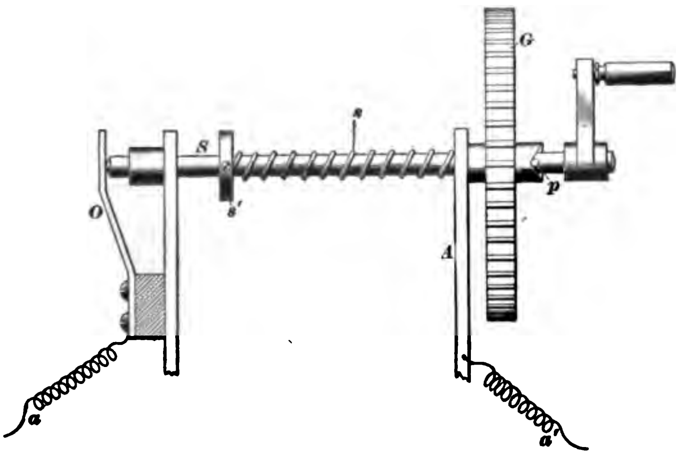


FIG. 78.

in more extensive use than any other is that known as the Williams automatic shunt, manufactured by the Western Electric Company, and used on nearly all the instruments of the American Bell Telephone Company. This is shown in Fig. 78, in which the large gear-wheel G is loosely mounted upon the crank-shaft S, and is free to turn thereon through a small portion of a revolution. The crank-shaft S is normally pressed towards the left by a spiral spring s bearing at one end against the end-plate A of the generator, and at its other end against the collar s' rigidly secured to the crank-shaft.

The hub of the gear-wheel G is provided with a V-shaped notch in which rests a pin p secured directly to the crank-shaft *S*. A spring *O*, which is connected with one terminal *a* of the armature winding, rests against the end of the shaft *S* when at rest, and therefore completes a short circuit around the armature whose other terminal *a'* is connected directly with the frame of the generator as in the ordinary manner. When the crank is turned, the pin *p* rides out of the notch in the hub of the gear-wheel, and in so doing pulls the shaft against the pressure of the spring *s* out of contact with the spring *O*, thus breaking the low-resistance path, or shunt, around the armature and leaving the latter effectively in the line.

201. Centrifugal Shunt.—In Fig. 79 is shown another form of automatic shunt, known as the Post, depending upon the centrifugal action due to the rotation of

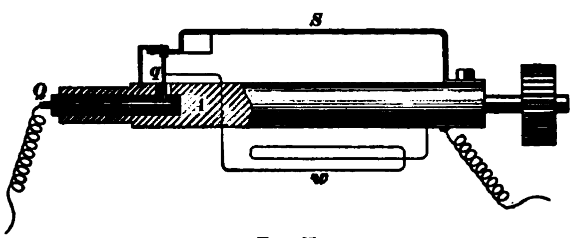


FIG. 79.

the armature. In this figure, the armature shaft *A* is shown, the coil of the armature being represented diagrammatically by the wire *w*. This coil, it will be seen, terminates on one side in the armature shaft and on the other side in the pin *q* connected with the pin *Q* in the ordinary manner. *S* is a spring secured at one end to the armature shaft and normally bearing at its other end on the pin *q*, so as to form a short circuit between that pin and the armature core. When, however, the armature is rotated, the weighted end of the spring *S* breaks circuit with the pin *q*, due to centrifugal force, and thus breaks the shunt while the generator is in action. This form of shunt, depending as it does upon a single contact, which, owing to mechanical reasons, is necessarily light, has not proved altogether satisfactory in practice.

202. The Cook Shunt.—In Fig. 80 is shown the Cook shunt, manufactured by the Sterling Electric Company. A sectional view of the crank-shaft and bearings, together with the shunt-operating mechanism, is shown at (*a*) in this figure, while small detached views (*b*) and (*c*) illustrate the respective positions of the contacts while the generator is in motion and at rest. *B*, *B* are the bearings for the crank-shaft, these being supported by upwardly projecting arms from the end-plates of the generator. The large gear-wheel *G* is mounted on a hub *g''* which is rigidly secured to a

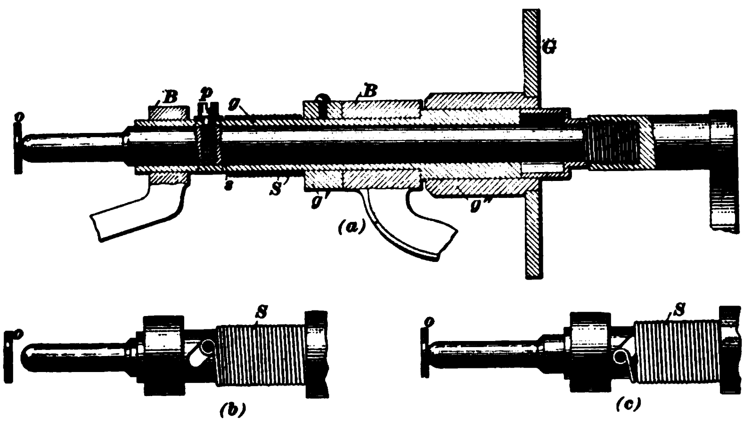


FIG. 80.

sleeve *g*. The sleeve *g* turns within the bearings *B*, *B*, and is itself free to turn on the shaft *s*, but can not slide sidewise in the bearings *B*, *B*. The connecting means between the shaft and the sleeve *g* is a spring *S* coiled around the sleeve, one end of which is fastened to a collar *g'* rigidly secured on the sleeve, while the other is fastened to a screw-pin *p* passing through a diagonal slot in the sleeve and into the shaft. This pin is normally held at one end of the slot by the tension of the spring, as shown at (*c*), and the shaft is thereby held in contact with the spring *o*, this contact completing the shunt around the armature. When, however, the crank is turned, the pin *p* rides against the sides of the slot against the tension of the spring *S* until it assumes the position shown at (*b*), and thus breaking the connection between the shaft and the spring *o* and removing the shunt from the armature. Turning the crank right-handed moves pin *p* right-handed, thus tending to wind up the spring *S*, and since the collar *g'* can not slide laterally, the pin with the shaft is moved to the right. It will be seen that the sleeve *g* and the large gear-wheel *G* remain at rest until the pin *p* reaches the end of the slot, as shown at (*b*), after which the sleeve and gear-wheel turn with the shaft.

THE HOOK SWITCH.

203. Functions of Hook Switches.—We have now considered the apparatus for sending and receiving both articulate speech and signals. These two sets of apparatus perform entirely separate functions, and although the two are never in use at the same time, both are absolutely essential to the successful working of an instrument. In order that a separate circuit need not be provided for the calling and the signaling apparatus, arrangements are made by which the two sets of apparatus may be alternately switched into and out of the line circuit. It is evident that during the idle periods of the instrument it is necessary that the call-receiving device—the ringer—shall be left in the circuit in order that an incoming call may be sounded. As soon, however, as a call is received or sent, there is no more need of the calling apparatus, and the telephone apparatus proper is then brought into circuit. The two are never left in circuit at the same time, because it would then be necessary, in signaling for the generator currents, to pass through the talking apparatus, and in talking, for the telephone or "voice currents" to pass through the signaling apparatus. The alternative switching of the talking and of the signaling apparatus into the circuit was at first accomplished by ordinary hand switches, but it was soon found that people could not be relied upon to operate them intelligently, and as a remedy to what seemed at first a most serious trouble, a device was designed to accomplish these changes of circuit automatically, without the volition of the user of the telephone. Such devices are termed automatic switches, or, more frequently, hook switches, and are usually operated by the weight of the receiver.

204. The hook switch usually consists of a lever pivoted at one end and provided with a hook or fork forming a convenient support for the receiver. The lever is normally pressed upwards by a spring, the strength of which, however, is not sufficient to hold the lever in its raised position when subjected to the weight of the receiver. By the up-and-down motions of the lever certain contacts are made or broken, which bring about the desired changes in the circuits.

CIRCUITS OF A TELEPHONE.

205. A primary knowledge of the operation and functions of the hook switch may be best understood by con-

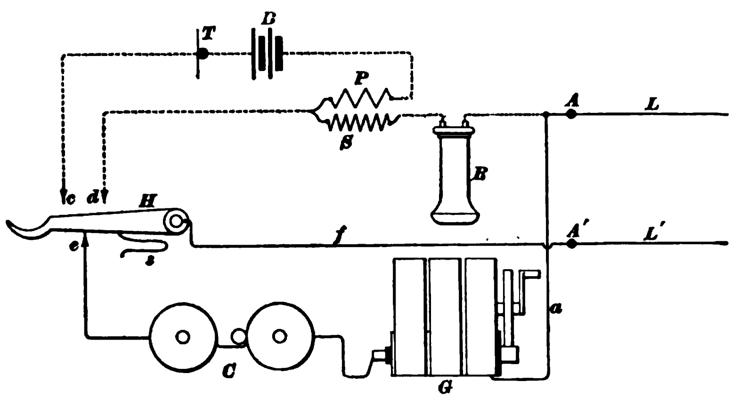


FIG. 81.

sidering the circuits of a telephone instrument. Such circuits are shown in a simplified form, for convenience of illustration, in Figs. 81 and 82, the former representing the circuits as they exist when the receiver is on the hook, and the latter the circuits when the receiver is removed from the hook. The circuits which are in operation in each case are represented by full lines, and those which are idle, by dotted lines. In Figs. 81 and 82, *A* and *A'* represent the binding-posts of the telephone instrument as a whole, in which the line-wires *L* and *L'* terminate. *H* is the hook-switch lever pressed upwards by the small spring *s* against

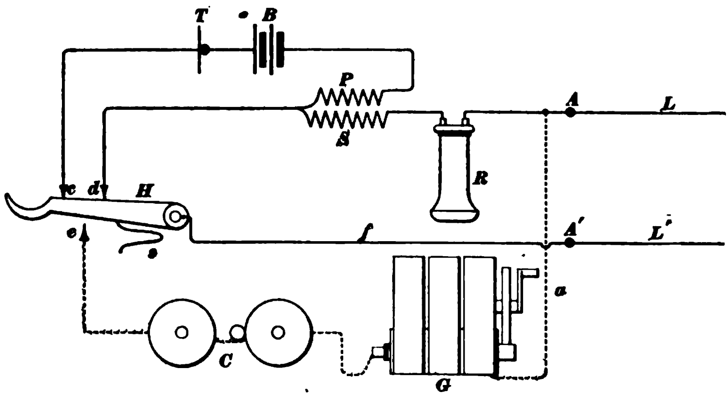


FIG. 82.

the two contacts *c* and *d*. When, however, it is subjected to the weight of the receiver, as shown in Fig. 81, the lever is depressed against the tension of the spring *s* in such manner as to open the contacts at *c* and *d* and to make a contact with *e*.

206. Hook Lever Down.—When the hook is in the position shown in Fig. 81, the circuit may be traced from the line-wire *L* and binding-post *A* through the wire *a* to the generator, thence through the bell *C* and to the contact point *e* of the hook switch. As this point is in metallic contact with the lever *H*, the circuit is rendered complete through the wire *f* to the binding-post *A'* and to the line-wire *L'*, or to the ground, in case a ground return is used. In this position, the circuits containing the talking apparatus, consisting of the transmitter *T*, the battery *B*, the receiver *R*, and the primary and secondary coils *P* and *S*, are all open at the contacts *c* and *d*.

207. Hook Lever Up.—When the receiver is removed from the hook, the lever rises and breaks contact with the point *e*, thus rendering the branch of the circuit containing the generator *G* and the polarized bell *C* inoperative. By making contact, however, with the points *c* and *d*, two new circuits are closed, one of which may be traced from the line-wire *L* through the receiver *R* and the secondary coil *S* of the induction-coil to the point *d* of the hook, and thence by means of the hook lever and the wire *f* to the line-wire *L'* or ground, as the case may be. Thus the circuit for incoming voice currents from a distant station or for outgoing voice currents, originated in the secondary coil *S* by induction from the primary circuit *P*, is made complete. Another circuit containing the transmitter *T*, the battery *B*, and the primary *P* is closed by virtue of the hook lever making contact with both the points *c* and *d*. This is the local circuit of the telephone instrument in which the transmitter acts, as already described. This method of connecting the magneto-bell and telephone is often known as the Post diagram.

The circuit closed when the switch is down is known as the calling, or signaling, circuit; the circuit containing the receiver and the secondary winding of the induction-coil, and closed when the switch is up, as the secondary talking circuit, or simply the secondary circuit; and the circuit containing the transmitter, battery, and the primary of the induction-coil as the local transmitter, or primary talking circuit, or simply the primary circuit.

208. Western Electric No. 2 Telephone Circuit.—The method of connecting the magneto-bell and telephone shown in Fig. 83 is known as the Western Electric, No. 2 diagram. It is now used quite extensively by the Bell Telephone Company. The circuits can be readily traced by the reader. It will be noticed that the signaling circuit and the secondary talking circuit are always connected to the line-wires; neither *are ever on open circuit*, but each is short-circuited when it is not in use by the wires *m* and *n*, respectively. That is, when the switch *H* is down, the receiver and secondary coil are short-circuited by the wire *n*, the primary circuit being on open circuit; when the switch is up, the generator and bell are short-circuited by the wire *m* and the primary circuit is closed at *c*.

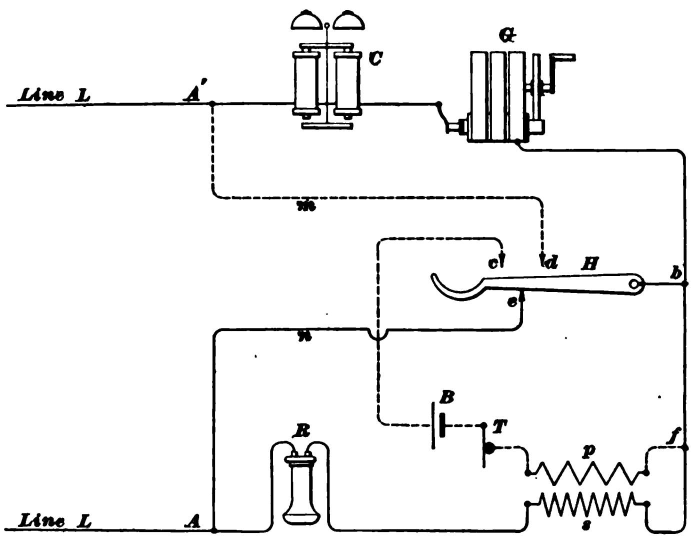


FIG. 83.

COMMERCIAL HOOK SWITCHES.

209. The Warner Switch.—This is the switch used by the American Bell Telephone Company in nearly all its telephones, and is shown in Fig. 84. The lever *l*, carrying the hook forming the receiver support on its outer end, is pivoted to a bracket screwed to the inside of the magneto-box. The lever is held in the position shown

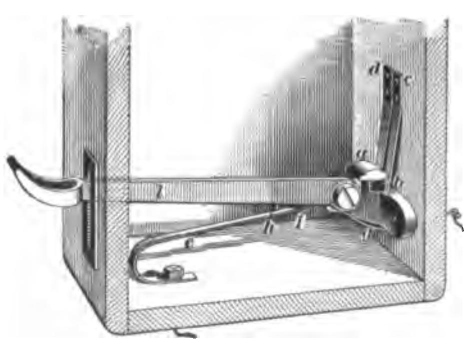


FIG. 84.

when released from the weight of the receiver, by the action of the spring *e* pressing against the rubber knob *f*. In this position, a knife-edge formed on the short arm *a* of the lever makes contact with the springs *c* and *d*, which press outwardly from the side of the box, thus not only putting them in metallic contact with the lever, but electrically connecting them with each other. When the hook is depressed, the metallic pin *h* on the under side of the lever makes contact with the spring *e*, thus making electrical contact between the lever and that spring. At the same time, the knife-edge on the short arm *a* of the lever is withdrawn from contact with the springs *c* and *d*, which now rest against the hard-rubber block *b* carried on the under side of the short arm of the lever, as shown. The spring *g* always presses against the rounded portion of the lever, so as to insure a perfect contact between it and the bracket, it having been found that the contact through the pivot screw could not be relied upon for transmitting the feeble voice currents. All contact points upon this hook are faced with platinum, in order that they may be bright and clean and not subject to corrosion either from atmospheric influence or from sparking, which often takes place when the circuit is broken. A slight rubbing action also takes place between all the surfaces when the circuits are made or broken, which further tends towards preserving clean, bright contacts. This hook switch, although very simple, represents a development attained only after several years of actual experience, and it forms a good example of the nicety of detail which must be employed in the design of even the simplest parts of telephone apparatus.

210. Prevention of Poor Contacts.—One of the chief sources of trouble in a telephone is the hook switch, where it is not properly designed and constructed. The slightest particle of dust, entirely invisible to the eye, lodging between the contact surfaces on the springs and on the lever, will frequently cause an open circuit or a point of such high resistance that it amounts to the same thing. Again, a loose contact between the two springs, especially if it be in the local circuit with the transmitter battery, may cause intermittent and exceedingly disagreeable noises in the receiver which may entirely prevent the transmission of speech. As a rule, the signaling contacts, that is, those closed by the switch to complete the signaling circuit when the telephone is out of use, do not give so much trouble as the talking contacts, that is, those which are used to complete the primary and secondary talking circuits.

It will be noticed that any one of the springs *c*, *d*, or *e* bears alternately upon a rubber block when the hook is in one position, and upon a metallic contact on the lever when the hook is in the other position; thus the spring *c* bears upon the rubber block *b* when the hook is depressed and upon the metallic knife-edge on the short arm *a* when the hook is raised. This change of contact is, however, accomplished without dragging the spring alternately over one and then over the other; that is, the rubber block *b* and metallic knife-edge *a* never rub or touch the same part of the spring *c*. Many hooks have been designed which brought about changes in the circuits which neglected this point, and have always resulted in failure, because, in passing from the rubber to the metal surface, a small portion of the rubber would adhere to the metal, thus forming a partially insulated path; again, in passing from the metal to the rubber, the metallic particles from the former would be deposited upon the latter, thus forming on it a partially conducting surface. Such sliding contacts as these should be carefully avoided, and this is cleverly done in the Warner switch. Another serious difficulty which often arises in hook switches is that due to cutting between the various contact surfaces. This will invariably occur where a long sliding contact takes place between the lever and the various springs. For this reason, those hooks which depend for their action upon a lever sliding for a considerable distance over the surfaces of the contact springs should be avoided. The amount of energy available for moving the switch is limited by the weight of the receiver, and it frequently happens that where these long sliding contacts take place, the surfaces become so roughened, due to the cutting action between them, that the restoring spring does not have the power to raise the lever when the receiver is removed, or the receiver does not have the power to pull it down again when placed on the hook.

211. Another form of the long-lever type of switch, similar to the Warner, and made by both The Telephone Manufacturing Company and the Williams Electric Company, is

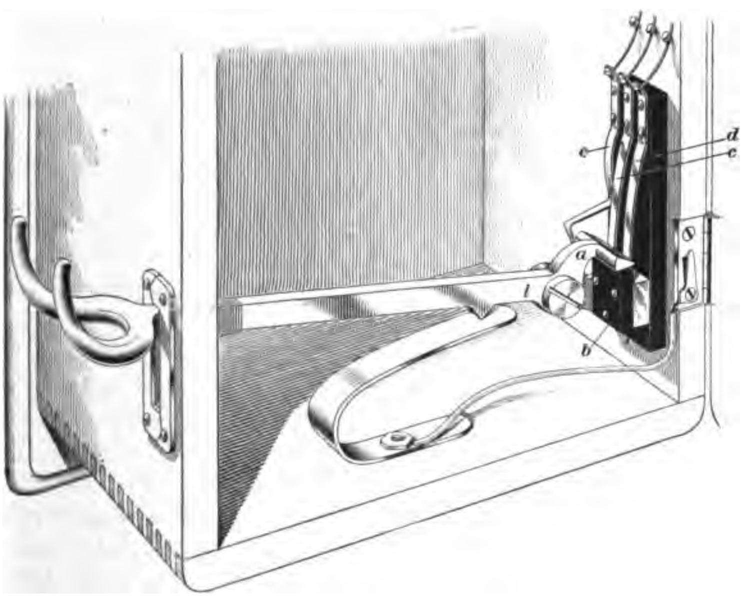


FIG. 85.

shown in Fig. 85. In this, all the changes of circuit are brought about by means of a double knife-edge upon the short arm *a* of the lever *l*. All the three springs *c*, *d*, and *e* rest normally; i. e., when the switch is down against a hard-rubber block *b* carried on the bracket which supports the lever, the two springs *c* and *d* forming the terminals of the talking circuit having their tips resting against the rear side of the block, while the spring *e* forming the terminal of the calling circuit rests against the forward side of the block. When the hook is up, the knife-edge makes contact with the surfaces of the springs *c* and *d*, completing the talking circuit and pushing them from their resting-place against the block. At the same time, the hook breaks contact with the spring *e*, which is allowed to rest against the forward surface of the block. The reverse conditions take place when the hook is depressed by the weight of the receiver. This hook does not use platinum contact points, but depends upon a very slight rubbing motion between the knife-edge on the short arm of the lever and the German-silver contact springs to keep the surfaces bright.

212. Western Telephone Construction Company's Switch.—An entirely different form of hook is shown in Fig. 86, which is manufactured by the Western Telephone Construction Company. In this, the lever *A* upon which the receiver is supported forms no part whatever of the electrical circuit. This lever is pivoted at *a* in a bracket *B* secured to the outside of the generator box. On the short arm of the lever is pivoted an antifriction shoe *S* of German silver, against which the main spring *L* bears. This spring, which is secured to the inner surface of the generator box, is of ordinary rolled brass, and bears with sufficient force against the shoe *S* to normally press the short arm of the lever *A* outwardly, and thus raise the hook when it is not subjected to the weight of the receiver. When the receiver is in place, however, the hook is forced downwards and the shoe presses the spring *L* away from the wall of the box. The spring *L*, which forms one terminal of the line circuits, performs the same functions, electrically speaking, as the lever *l* in the switches already discussed. Its upper end, when the receiver is on the hook, is pressed against the spring *e* forming the terminal of the signaling circuit; but when the receiver is removed from the hook, it breaks contact with the spring *e* and comes into contact with the spring *d*, which it also presses into contact with the spring *c*. These two latter springs form, respectively, the terminals of the primary and secondary circuits in exactly the same manner as already described, and therefore the

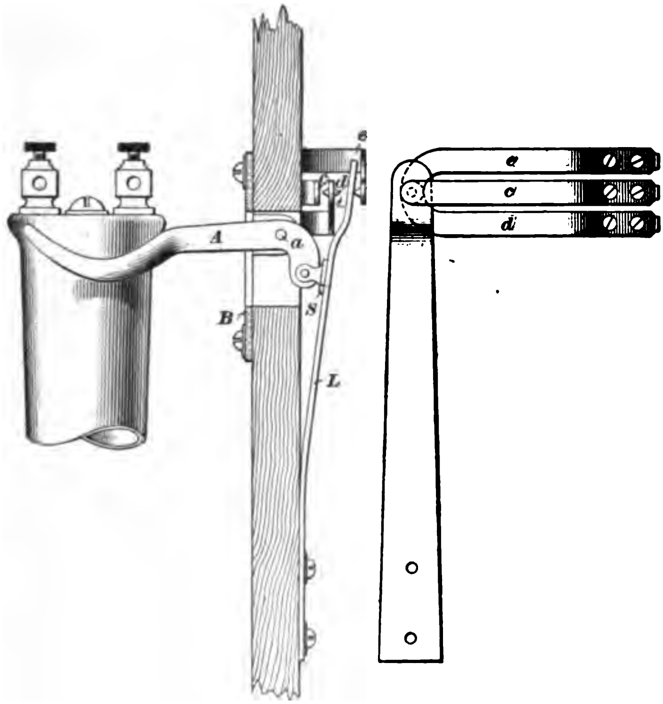


FIG. 86.

local transmitter and secondary talking circuits are completed. Both sides of the spring L and one side of c are faced with platinum on the surfaces where the springs e and d make contact. These springs are also provided with platinum contact points, so that the surfaces between all contacts in this switch are of that metal. This hook, as recently manufactured, is thoroughly efficient, its simplicity being in its favor. Again, the fact that no pivotal points are included in any of the circuits is another point in its favor.

213. As an illustration of the important part which platinum may play in contacts and of the trouble which may be brought about by cutting, due to friction between the various parts, it may be stated that this switch was a dismal failure until all its points were made of platinum and until the shoe *S* was used to reduce the cutting, and therefore the friction, between the lever and the spring *L*.

COMPLETE TELEPHONE INSTRUMENTS.

CIRCUITS.

214. A complete telephone instrument includes all of the apparatus necessary for transmitting and receiving both speech and signals, and the auxiliary switching device for bringing either one or the other sets of apparatus into use, as desired. The circuits in which these various parts are connected have already been shown in a general way in Figs. 81 and 82. In those figures, however, all details of the circuits were omitted for the purpose of rendering the general principles involved more clear.

SERIES INSTRUMENTS.

215. By a series instrument is meant one in which the ringer and the generator when in operation, and therefore not short-circuited by the automatic shunt device, are connected in series with each other across the line-wires when the lever switch is in its normal, down position.

In Fig. 87 are shown the various parts of a complete telephone, connected in circuits as they are in actual practice in subscribers' telephone sets. *G* is the magneto-generator, *C* the ringer, *R* the receiver, *T* the transmitter, *H* the hook switch, *B* the battery, and *S* and *P* the secondary and primary, respectively, of the induction-coil. *A* and *A'* are the binding-posts of the instrument, to which the line-wires are attached.

216. Calling Circuits.—When the receiver is on the hook *H*, the circuit through the instrument may be traced

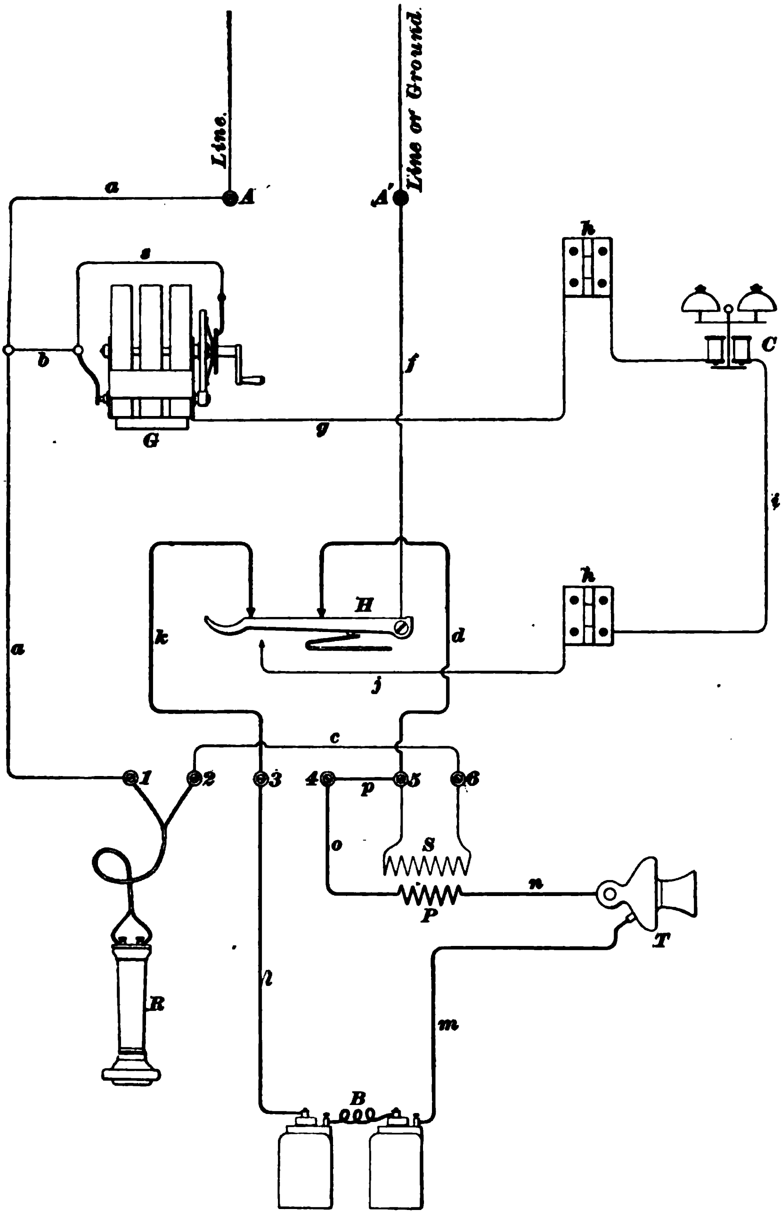


FIG. 87.

as follows: Starting at binding-post *A*, a current will pass by wire *a* and wire *b* to the armature spring of the generator; two paths will then be presented, one through the armature winding to the frame of the generator and to the wire *g*, and the other through the shunt wire *s*, shunt spring and collar on the generator shaft to the frame of the generator and wire *g*, as before. As the latter path is a short circuit of almost no resistance, especially when compared to that of the armature winding, practically all the current will pass through it. From the wire *g* the current will pass through the upper hinge *h* on the lid of the box, thence through the coils of the polarized bell *C*, and thence by wire *i*, lower hinge *h*, and wire *j* to the lower contact of the switch. When the lever is depressed, the current will pass through it and by wire *f* to the return side of the line or to ground, according to whether a metallic circuit or a grounded circuit is used. An alternating current from another station, passing over this path, will cause the bell to ring, and thus give the desired signal. In sending a signal, the circuits will be the same as in receiving one, with the exception that the shunt formed by the shunt wire *s* will be broken, due to the turning of the crank.

217. Talking Circuits.—After having sent or received a signal, the receiver is removed from the hook, and the conditions of the circuits are then as shown in the figure, the signaling circuit being broken at the contact point on the under side of the hook, while two other circuits containing the talking apparatus are closed by the contacts on the upper side of the hook. Starting at binding-post *A*, the current coming over the line would pass through wire *a*, receiver *R*, wire *c*, secondary winding *S*, wire *d*, to the upper right-hand switch contact, to hook lever, and thence by wire *f* to binding-post *A'*. This secondary circuit contains only the receiver and the secondary winding of the induction-coil. Another circuit is also closed by the rising of the switch-lever containing the battery, the primary winding of the induction-coil, and the transmitter. The wires forming the primary circuit are shown by heavy lines, and beginning at the battery may be traced as follows: battery, wire *m*, transmitter *T*, wire *n*, primary winding *P*, wires *o*, *p*, and *d* to the upper right-hand contact of the lever, through the lever to the upper left-hand contact, and by wires *k* and *l* back to the battery.

218. Connections in Generator Box.—It is customary, merely on account of convenience, to mount the generator, the receiver, and the hook switch all in one box, which is usually placed at the upper part of the instrument, the transmitter and battery being put in separate places. In order to facilitate the attachment of the talking apparatus proper, it is customary to place a row of binding-posts, *1* to *6* inclusive, on the lower part of the generator box. The arrangement of the various parts of the apparatus with respect to these binding-posts varies considerably, according to the make of the instrument; but the custom of the Bell Company, and also of most other companies, is to devote the left-hand pair, *1* and *2*, of the binding-posts to the receiver terminals; the center pair, *3* and *4*, to the terminals of the primary circuit, and the right-hand pair, *5* and *6*, to the terminals of the secondary of the induction-coil.

219. Arrangement of Apparatus in Generator Box.—In Fig. 88 is shown a front view of the complete magneto-bell as now manufactured by the Williams-Abbott Company. The ringer, which is illustrated in detail in Fig. 75, is mounted on the lid of the box, its hammer projecting through to engage the gongs *B* on the outside. Connections are made to the ringer through the hinges of the box in a manner that will be described in detail later. The generator is mounted in the bottom of the box and set well to the rear, it being clamped in place by the bolts *b*, *b*, which pass entirely through the generator and through the backboard of the box, where they are secured by nuts. Sufficient clearance is left above the generator for the ringer to occupy when the door is closed. Mounted directly in front of the generator and in the lower part of the box is the hook switch *H*, which is of the long-lever type and of a special

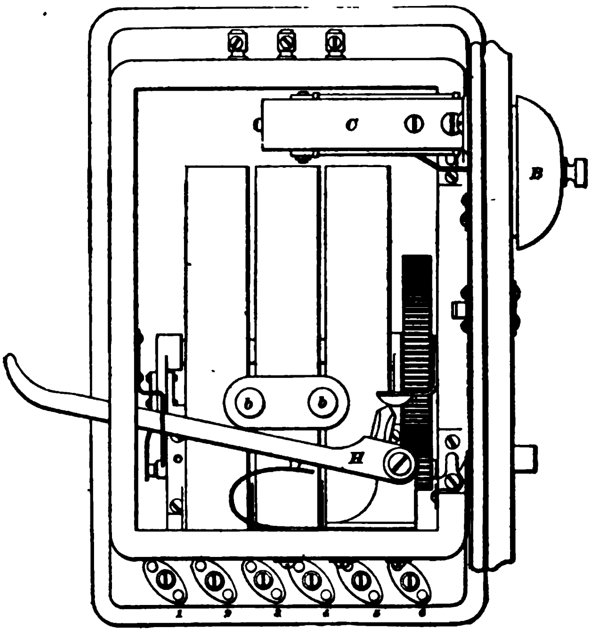


FIG. 88.

design recently adopted by this company. The binding-posts *1*, *2*, *3*, *4*, *5*, and *6* are secured to the bottom of the backboard on the outside of the generator box, connection being made from them to the various parts within.

This arrangement of the parts within the box is typical of most good telephone instruments, although the parts are sometimes changed in their relative positions to a considerable extent. In instruments using the short-lever hook switch, such as is shown in Fig. 86, the switch mechanism is mounted on the left-hand side of the box, the hook usually projecting out of the box at a point considerably higher up than that shown in Fig. 88. This latter arrangement has the advantage of making possible the use of a shallower box, but in many forms of short-lever hooks, the contacts are so crowded together that it is almost impossible to repair them without taking out the generator—an obvious disadvantage. The long-lever hooks, when properly designed, have all of their contacts within easy access when the door is opened.

220. Complete Western Electric No. 2 Telephone Set.—In Fig. 89 are shown the various parts of a

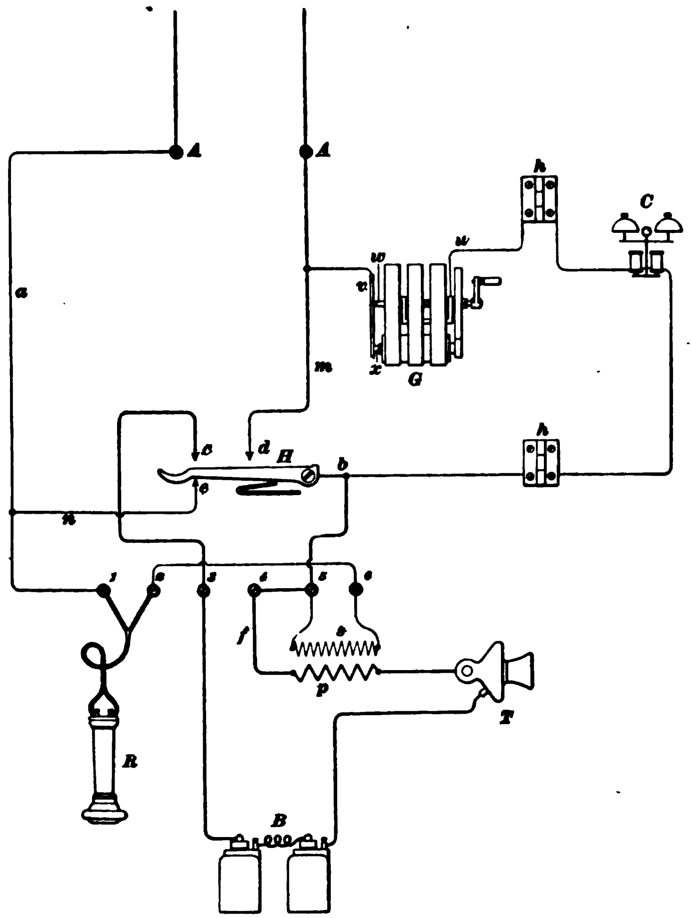


FIG. 89.

complete Western Electric No. 2 telephone, connected as they are in practice. The Williams automatic cut-out is indicated in connection with the generator. The shunt, which short-circuits the armature coil, starts at the spring *v*, goes through the shaft *w* of the large gear-wheel to the frame of the generator, and out by the wire *u*. When the handle of the generator is turned, *w* is drawn away from the spring *v*, thus opening the armature-shunt circuit, and the path for the current is then from the spring *v* to the insulated end *x* of the armature coil, through the armature coil and the frame of the generator to the wire *u*. The connections and lettering are exactly the same as in Fig. 83, in which unnecessary details were omitted for the sake of clearness. The reader can readily trace out for himself the circuits in the two positions of the hook switch.

221. Party Lines.—Such an instrument as that shown in Fig. 87 is termed a series telephone. It is sometimes necessary to connect more than one telephone instrument to one line, such a line being then termed a party line, or, more properly, a many-party line. Obviously, two methods present themselves of connecting telephones to such a line; one being to connect them in series, so that the circuit of the line will pass through one instrument, then through the next, and so on through the entire number. Instruments adapted for such use are termed series telephones, and are often said to be "looped" in the line. The other method is to connect the instruments in multiple, that is, in such manner that all the telephones are in parallel branches or bridges between the two sides of the line. As a matter of fact, the best practice now dictates the parallel connection of instruments with the line, and inasmuch as an instrument so connected forms a bridge between the two sides of the circuit, such instruments are called bridging instruments.

BRIDGING INSTRUMENTS.

In Fig. 90 is shown in detail the pieces of apparatus forming a complete bridging telephone instrument properly connected together in their proper circuits.

222. Talking Circuits.—The arrangement of the local circuit is in this case identical with that of the series instrument, the transmitter *T*, the battery *B*, and the

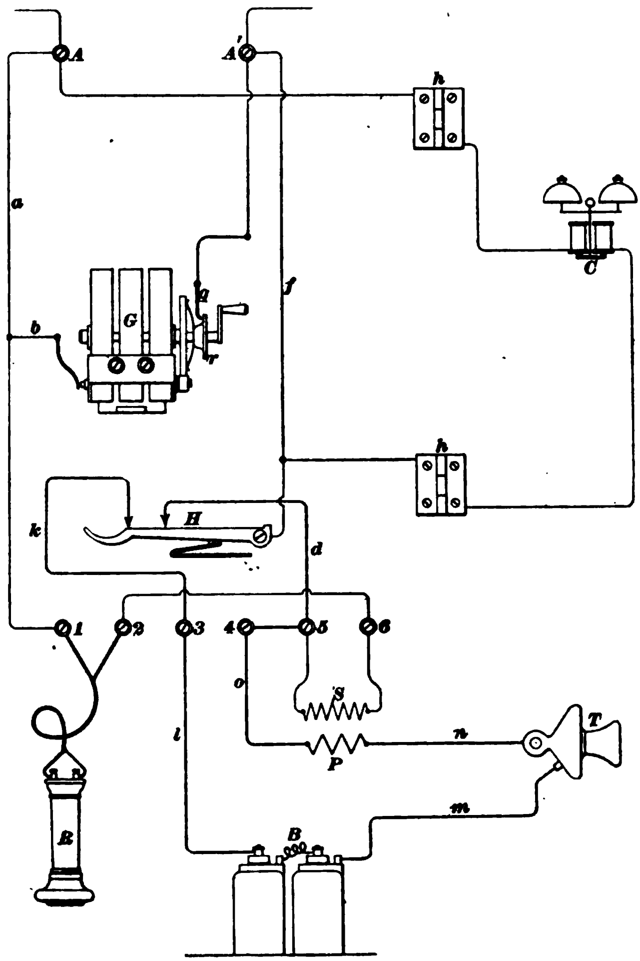


FIG. 90.

primary *P* of the induction-coil being connected together in series in a local circuit when the receiver is removed from the hook. In the same manner, it will be found that the secondary circuit containing the receiver *R* and the secondary winding *S* of the induction-coil are connected between the binding-posts *A* and *A'* in series when the hook is raised, as before; this circuit being from binding-post *A* by wire *a* to the receiver *R*, thence to the secondary winding *S* of the induction-coil, to the lever *H* of the hook, and thence by the wire *f* to the binding-post *A'*.

223. Calling Circuits.—The points wherein the circuits of a bridging instrument differ from those of a series instrument are found in the connection of the calling apparatus with the line. In the series instrument, Fig. 87, the generator and call-bell were placed in series between the two binding-posts, the circuit being opened by the lower contact point on the switch hook when the receiver was removed. In the bridging instrument, the call-bell *C* is in a permanently closed circuit between the two binding-posts *A* and *A'*, this circuit being traced from the post *A* through the upper hinge *h*, thence through the bell *C* to the lower hinge *h*, and by wire *f* to the binding-post *A'*. This circuit, in most makes of instrument, is never broken. The generator, instead of being in series with the call-bell and normally shunted, is connected in parallel with the bell across the two binding-posts *A* and *A'*, and is in a normally open circuit. This circuit is closed only when the generator is operated, this being brought about by reversing the shunt mechanism so that it maintains a normally open circuit instead of a short circuit. Thus, in Fig. 90, the spring *q* occupies a position on the opposite side of the disk *r* from that in Fig. 87, the arrangement being such that *only when the generator is operated is the circuit closed between r and q*. The circuit may be traced from the binding-post *A*, wire *a*, wire *b*, through the armature of the generator, and by disk *r* and spring *q* to binding-post *A'*.

224. Three Bridged Circuits.—It may be said that in the bridging instruments, the apparatus is arranged in three distinct parallel circuits between the binding-posts. The first of these circuits is permanently closed and includes the ringer, the second is normally open and includes the generator, and the third is also normally open and includes the receiver and the secondary of the induction-coil in series. It would appear at first that the presence of the ringer magnets as a permanent shunt around the talking apparatus would seriously interfere with the voice transmission. This would be the case were it not that the ringer magnets were wound with a very great number of turns of wire, usually so as to give them a resistance of 1,000 or 1,200 ohms. And, furthermore, by virtue of the self-induction and resistance of this coil, an almost impassable barrier is formed to the passage of the rapidly fluctuating voice currents, so that the transmission is not perceptibly affected.

The impedance of a 1,000-ohm ringer to currents whose frequency is about 15, such as produced by the ordinary hand-telephone generator, is about 1,200 ohms, while to the talking current, whose average frequency may be taken at 300 periods per second, the impedance is a little over 4,000 ohms, and at 600 periods, a frequency quite often attained, it becomes about 8,000 ohms. Thus, it is evident that the ringer acts only as a very high resistance shunt around the talking circuit when that is in use, allowing only an inappreciable part of the talking current to leak through it instead of flowing through the receiver. To the ringing current, however, the impedance is but little larger than its resistance.

The theory of bridging instruments and their practical application to party lines will be considered under the heading of "Party Lines."

DETAILS.

WIRING.

225. The manner in which a telephone is "wired up" plays an important part in the future efficiency of the instrument. The greatest precaution should be taken that none of the wires lie so close together as to form crosses between them, and a not less important point is the provision against breaks in the various circuits. The method of wiring the inside of a telephone box by the use of small staples is a good one, provided it is carried out with sufficient skill and care. A good grade of insulated wire should always be used, and two wires should never, under any circumstances, be placed under the same staple. It not infrequently happens that two staples over different wires, although apparently out of contact, make contact with each other under the surface of the wood, and thus form crosses, which it is often very difficult to locate. This should be guarded against.

226. Lacing Method of Wiring.—In a plan of wiring recently adopted by several companies, the wire is not insulated, and is held in its proper position by virtue of its being laced back and forth through the backboard of the generator box. By this method it is very easy to draw the wires tight before soldering them to their proper terminals.

227. Cleat Wiring.—Another method is by the use of wooden cleats placed at the intersection between the backboard and the sides of the generator box, the cleats being provided with suitable grooves, through which the wires are led. These cleats are held in position by screws, and may be readily removed in case of needed repairs.

228. Soldering Joints.—All joints, either between two wires or between a wire and a metallic surface, such as a spring or hinge, should be carefully soldered. In soldering, the flux used should not be an acid; but resin or certain other non-acid soldering salts should always be used instead. The reason for this is that acid, when smeared over the surfaces of the metal and the wood, causes them to present an unsightly appearance; and, what is more serious, the acid frequently corrodes the wires to such an extent as to entirely break the circuit.

229. Hinge Joints.—The ringer is usually mounted upon the cover of the generator box, and it therefore becomes necessary to provide flexible connections to it. These are usually made through the hinges of the box, and unless certain precautions are taken, the contact through them is apt to become very poor. To remedy this, many companies now use the device shown in Fig. 91, in which *a*, *a* are clips of spring metal, each secured under one of the screws holding one side of the hinge in place. When the hinge is closed, these clips are pressed firmly together, thus securing a firm and lasting connection. Another way of making this connection is by means of a piece of a flexible conductor, such as lamp cord, attached rigidly at one end to the inside of the box, and at the other to the inside of the cover.

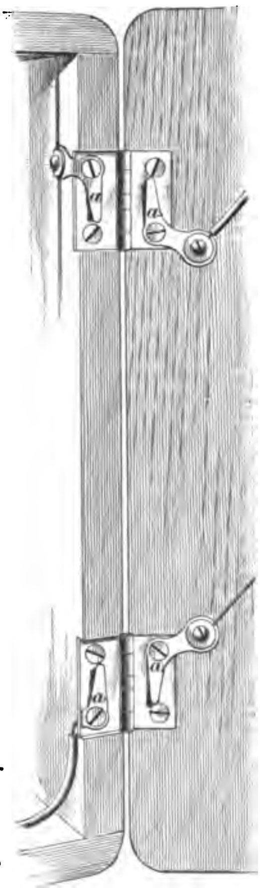


FIG. 91.

230. In permanently securing wires to binding-posts, as on the inside of the box, the custom has been to clamp the wire between two copper washers by means of the screw which passes through the wood of the box and holds the binding-posts in position. This method is not altogether satisfactory, and frequently causes open circuits, by reason of the fact that wood often shrinks under the pressure of the screw and thus loosens the contact between the washers and the wire. A better method is to solder the wire directly to the binding-post or to the screw entering the binding-post; and in doing this, care must be taken that the wood is not burned to such an extent as to loosen the post. Where the screw passes through metal instead of wood, it is safe to make the connection without soldering, because there is no danger due to shrinkage.

FITTINGS.

231. Binding-Posts. — Binding-posts are used for joining wires where it is probable that the conductors will at some future time require to be disconnected. The matter of connecting wires permanently with the binding-posts which are to form their terminals has already received some attention. The binding-post itself, however, must be capable of securely holding another wire in such manner that the connection will always be firm and not liable to work loose from any cause whatever. The binding-posts of receivers are, perhaps, subject to the most severe use, these being constantly subject to strains due to the constant handling of the receiver. A good form of receiver binding-post is shown in Fig. 42. In this, the terminal of the receiver cord, or the wire to be connected, is passed through the stem of the post, and is then securely clamped in position by means of the collar *C* pressed against it by means of the thumb-nut *N*. Such a post subjects the cord terminal, or the wire to be attached, to a bending strain, which affords a very perfect connection.

Another form of binding-post recently brought into use is shown in Fig. 92. In this, the base of the post is

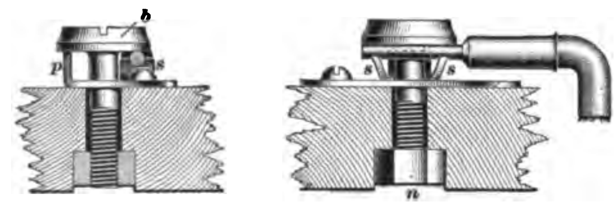


FIG. 92.

formed of a sheet of spring German silver, having two upwardly turned spring clips *s*, *s* provided on their tops with notches in which the receiver-cord tip or wire may rest. The screw *b* engaging the nut *n* on the opposite side of the material to which the post is to be attached is provided with a large, flat head adapted to bind firmly against the cord tip or wire and to press it more securely against the clips *s*, *s*. As the screw is forced down, the clips yield, owing to their elasticity, until finally the head of the screw comes into contact with the upwardly turned lug *p*, also on the base-plate, against which it engages by friction, thus preventing its working loose. The firm connection made by this post will be independent of the shrinkage of the wood or other materials through which it passes, as long as its shrinkage is not so great as to allow the clips *s*, *s* to resume their normal position. The space due to the shrinkage of the wood will be taken up by the elasticity of the clips, which will still clamp the cord tip firmly against the head of the screw.

232. Receiver Cords. — In order to allow for the handling of the receiver, it is necessary to connect it with the body of the telephone by a flexible conductor adapted to allow a free movement of the receiver and at the same time to maintain electrical connection between its terminals and the interior circuits of the telephone box. The cord must necessarily contain two conductors, one leading to each terminal of the receiver. These conductors are usually formed of twisted or braided tinsel strands provided with an insulating covering of silk or cotton and afterwards laid together and covered with a braiding of worsted, binding the two conductors together. As a precaution against mechanical injury to the conductors, it is not uncommon, after the first layer of insulation has been put on, to encase each conductor in a spiral wrapping of spring brass wire. This wire forms no part of the conductor, but serves as a flexible mechanical protector for the conductor within. The two armored conductors are afterwards braided over in the manner before described.

233. A good receiver cord is made as follows: The conductor is composed of a large number of tinsel strands with which a few fine copper wires are woven in order to impart a greater strength. About this conductor is wrapped a layer of floss silk; this is preferably put on as a wrapping instead of as a braiding, because the former serves to bind the fine ends of the conductors closely together, thus affording them no chance to project through the insulation and form a short circuit with the companion conductor. Over this layer of silk is placed a braid of linen or hard cotton, outside of which is placed the armor of spring brass wire. The two conductors are then laid together and served with a braiding of colored worsted, thus giving them the well-known appearance.

234. Cord Tips.—The most difficult matter in the construction of receiver cords is to so attach the tips to the conductors that the strain due to the handling of the receiver will not fall upon the conductor itself, but upon the braiding, and at the same time to provide against breakage at the juncture of the conductor and the tip, due to the sharp bending that is likely to occur at that point. One of the best methods of overcoming this difficulty is shown in Fig. 93. *A* is a pointed piece of wire forming the tip of the

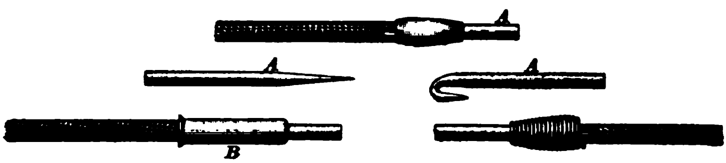


FIG. 93.

cord. The pointed end of this is inserted into the conductor of the cord, and passed out through the braid, and bent over upon itself so as to form a hook, as shown. This hook is then closed by pressure with a pair of pincers and the end wrapped with thread, after which the thimble *B* is slipped in place over the hook and securely soldered. This thimble is of such size as to fit closely over the external portion of the cord, therefore rendering it impossible to pull the tip off without tearing through the external braiding, which in itself possesses considerable strength. Instead of the thimble *B* a wrapping of wire may be used, as shown in the lower right-hand view in Fig. 93.

235. Woodwork. — The woodwork forming telephone cabinets or boxes is usually of walnut, although oak is coming into increasing favor. Mahogany, cherry, sycamore, and other varieties of wood are also occasionally used where it is desired to match the furniture and fittings of the rooms in which they are to be placed. The prime requisite for wood for this purpose is that it shall be thoroughly seasoned and free from knots and checks. The custom has been, in the ordinary wall instrument, to make the generator box and the box containing the batteries of $\frac{3}{8}$-inch stuff; but this thickness is hardly sufficient to withstand the usage to which telephones are frequently put in shipment or in actual service, and a far better plan is to use $\frac{1}{2}$-inch wood, which makes a much more substantial construction.

236. Battery-Box.—In wall sets, the battery is usually mounted in a box placed upon the same backboard as the telephone and signaling instruments, and below them. Many different designs of battery-boxes have been used, but probably the most convenient is that shown at *E* in Fig. 95, the means for supporting the battery-jars being shown in Fig. 94. In this figure, a shelf of cast iron secured directly to the backboard is provided for the reception of the battery. The wires leading from the apparatus in the local circuit of the instrument are brought through the backboard at a convenient point, as at *a*, *a'*. After connecting the wires to the terminals of the battery, the battery-box proper is put in place, being held by clips *c*, *c'* engaging

FIG. 94.

against similar clips on the battery-box *E*. A downward pressure on the box serves to clamp it more tightly, while it may be removed at any time by striking it a blow from beneath. The advantages of this type of box are that all its parts are readily accessible, which is not the case where the box is secured permanently to the backboard, the lid only being removed to allow access to the cells. Inasmuch as the top of the box is nearly always used to a greater or less extent as a writing-desk, the downward pressure on the lid will only serve to clamp it tighter, whereas, in the separate lid, the reverse is frequently true.

FORMS OF TELEPHONE SETS.

WALL SETS.

237. Generator Box.—The most common form of telephone instrument is that shown in Fig. 95. In this, the calling apparatus and hook switch are contained in the upper box *G*, the apparatus there being wired as already described. The terminals of the circuit going to the lines are brought out to the two binding-posts *A* and *A'*, the remaining terminals being carried to the six binding-posts mounted upon the lower projecting portion of the backboard *G'* of the generator box *G*. The entire generator box is secured to the backboard *D* of the complete telephone by means of the screws *g*. In the best forms of instruments, no wires pass through both the backboard of the generator box and the backboard *D*, as this causes much trouble in removing the generator box from the backboard when repairs or the renewal of parts are necessary. In the construction shown, the only wires that lead from the generator box terminate in the binding-posts mentioned, so that in case it is necessary to remove the box from the backboard, the wires may be disconnected by pulling them out of the binding-posts,

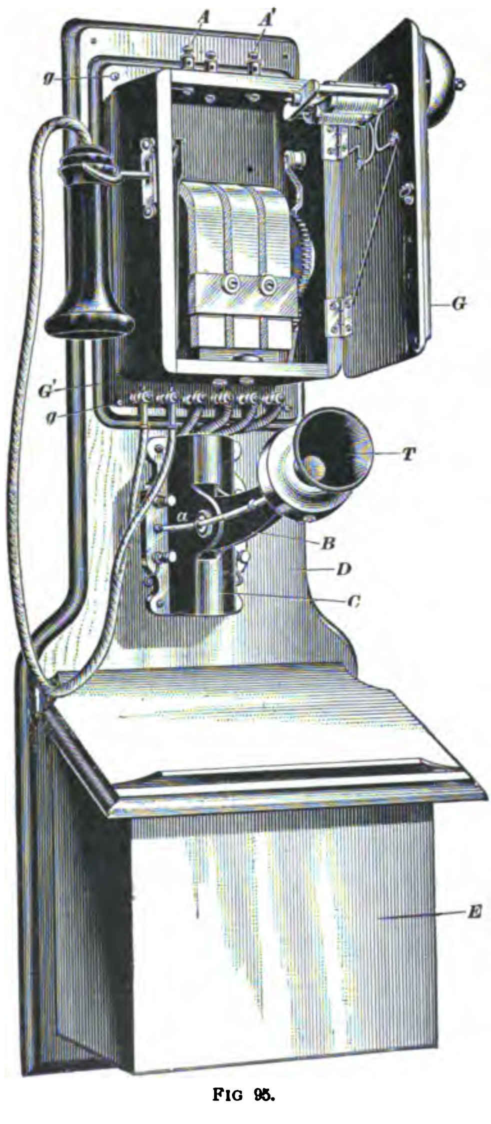


FIG 95.

after which the four screws *g* may be removed without fear of breaking any connections.

238. Transmitter and Coil.—The transmitter *T* is mounted upon the end of an adjustable arm *B* pivoted in the cast-iron bracket *C* secured to the backboard *D*. This bracket is usually made with a hollow base, in which the induction-coil is mounted, the terminals of the primary and secondary circuits being preferably brought out to binding-posts mounted on, but insulated from, the bracket itself. This construction allows the removal of the transmitter arm, with base and coil attached, without breaking any connections other than those terminating in the binding-posts. The two binding-posts forming the terminals of the secondary are connected directly with the two right-hand binding-posts in the lower row of six on the generator box. These connections may be made by curls or "pigtails" of wire directly on the front of the backboard, or by passing the wires from the binding-post on the generator box through the backboard, and bringing them out again to the front at points opposite the binding-post on the transmitter base. This latter construction gives a somewhat neater appearance, although the connections are not so easily traced by the eye. "Pigtails" can be made by coiling the wire around a lead-pencil and then slipping the pencil out of the coil so formed.

239. Connections Between Generator Box and Transmitter.—The same remarks apply to the binding-posts forming the terminals for the primary or local circuit. One of the center pair of binding-posts on the generator box is connected directly with one of the primary binding-posts on the transmitter arm. From this post, the circuit passes through the arm itself to the transmitter, thence back, by means of a flexible cord *a* held alongside of the transmitter arm, to one terminal of the primary coil within the base, from which the circuit passes to the other primary binding-post on the base. This latter post is connected through the backboard with one terminal of the battery in the box below, the other terminal of which is connected directly with the remaining binding-post of the center pair on the generator box. These circuits will be made more clear by referring to Fig. 87.

The battery-box *E* forms the lower portions of sets of this kind, and is preferably made according to the design shown in Fig. 94.

PORTABLE-DESK SETS.

240. For business men who wish to be able to use the telephone without leaving their desks, the form of instrument shown in Fig. 96 is very convenient. This set is typical of many. The hook is usually adapted to bring about the same changes in circuits as those already described, but are necessarily somewhat modified in their mechanical form in order to be available for use in this form of instrument. The hook lever usually projects from the side of the standard that supports the transmitter, and in the form shown is normally pressed upwards by a rod extending through the tubular standard and bearing against a long, flat spring on its lower end. This spring maintains the rod normally in its upward position, but is pushed downwards by the lever acting against the rod when the receiver is upon the hook. The movements of this spring, brought about by the action of the hook lever,

FIG. 96.

are caused to make and break the circuits in precisely the same manner as is done by the main spring L in the hook shown in Fig. 86.

241. In desk sets of this type, the induction-coil is usually mounted in the base of the standard supporting the transmitter and receiver. The generator and ringer, or whatever calling apparatus is used, is mounted in a separate portion of the desk, so as to be out of the way, and yet within the reach, of the user. The connections between the calling apparatus and the talking apparatus are usually made by means of a flexible, silk-covered conducting cord containing four or five separate conductors, usually the latter number being required. This flexible cord, which is of course entirely separate from the receiver cord, serves merely to make the connections between the calling apparatus and the telephone instruments proper, the two being connected together in the same set of circuits, as has already been described.

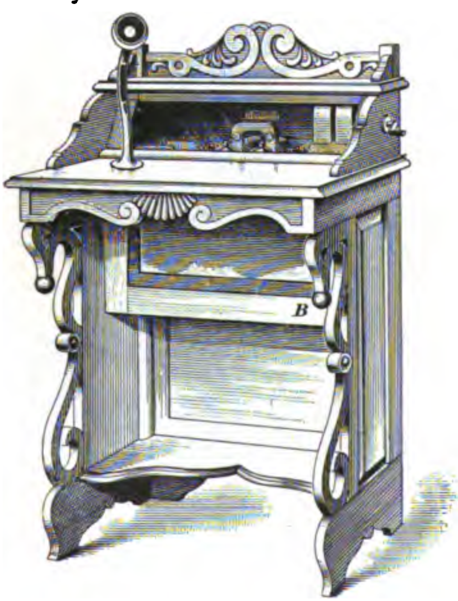


FIG. 97.

CABINET-DESK SETS.

242. Still another form of instrument which is convenient for large offices, for telephone booths, and for private residences, is the cabinet-desk set, one type of which is shown in Fig. 97. In this, the transmitter is usually mounted upon a gooseneck arm rigidly secured to the top of the desk. The generator, ringer, induction-coil, and hook switch are mounted upon the top of the desk, but are enclosed, as shown, by a cabinet having a glass front, so that all parts are clearly visible. The generator crank projects from the right-hand side of this cabinet, while the hook switch upon which the receiver is hung projects from the left-hand portion.

243. The batteries are mounted within a box just under the desk top, the front board *B* of which box is usually made removable, in order to gain access to the batteries. These desks are very convenient, and may, moreover, be made as ornamental as desired by incorporating in them the finest workmanship and design. The metallic parts of the calling apparatus are usually nickel-plated and highly polished, and when seen through a beveled glass front, present a very attractive appearance.

BATTERIES FOR TELEPHONE WORK.

GENERAL REQUIREMENTS.

244. Voltage.—The electromotive force best adapted for the operation of the ordinary granular-carbon transmitter is approximately 3 volts, although some transmitters, notably the solid-back, apparently work with a greater efficiency at as high a pressure as 6 volts. The Blake transmitter, however, attains its maximum efficiency with a pressure of less than 2 volts. For the above reasons, the ordinary granular-carbon transmitter is, as a rule, worked with two cells of the Leclanché type, placed in series, thus attaining an initial pressure of about 3 volts. The Blake transmitter is always worked with one cell of the same type of battery, it being found to produce the disagreeable humming sound already spoken of when subjected to a greater electromotive force than that of one cell. The American Bell Telephone Company and the American Long Distance Telephone Company use in connection with the solid-back transmitter two Fuller cells, thus attaining a pressure of 4 volts. At one time three such cells were commonly used in connection with this transmitter, but that practice is now being largely abandoned, as it is found that two cells give substantially as good results as three.

245. Internal Resistance.—It is desirable that a battery shall have as low an internal resistance as is possible, in order that the total resistance of the local circuit may be kept low, for the reasons pointed out in Art. **58.** A high internal resistance of the battery would not only reduce the amount of current flowing in the local circuit by Ohm's law, but it would also reduce the ratio which the maximum change in resistance, produced by the transmitter, bears to the total resistance of the circuit.

246. Current.—The current flowing in the primary circuit of a telephone will of course depend upon the resistance of the circuit, including the transmitter and the primary of the induction-coil, and upon the electromotive force of the battery. Owing to the peculiar property of carbon of lowering its resistance when heated, the current through a transmitter subjected to a constant electromotive force will gradually increase as the particles of carbon in the transmitter, which form the main resistance in the circuit, become heated. Inasmuch as the voltage of the battery rapidly falls off during the time when the local circuit is closed, its tendency to reduce the current is therefore in part counterbalanced by the fact that the resistance of the circuit is becoming lower, which would in itself, as shown, tend to increase the current. Whether or not the current through a transmitter actually falls off or increases as the transmitter is used depends upon the particular transmitter used and upon the degree to which the electromotive force of the battery falls off during use.

In general it may be said that the transmitters having but a single pair of electrodes, of which the Blake is representative, require about one-quarter of an ampere, while the granular-carbon transmitters, of which the solid-back is a type, operate well with as high a current as one ampere.

247. Recuperative Power.—A telephone battery is subject to rather severe use, especially so if the instrument is used frequently during the day. While in use it is working through a circuit of comparatively low resistance, the average length of time of use being from one to five minutes. The ordinary primary cell will, under these circumstances, be affected to a large degree by polarization, which results in a considerable reduction of the electromotive force; and although the resistance of the transmitter will be lower, due to its heating, this reduction in the electromotive force may cause a decrease in current. During any one period of use, not excessive, however, the resistance of the transmitter falls to such an extent that the current at the end of the period may be as great, or even greater, than at the beginning, notwithstanding the loss of voltage.

If, during the periods of disuse, the battery regains its strength so that at the beginning of the next period of use its voltage is normal, the same cycle of events will be repeated without impairing the efficiency of transmission. On the other hand, if, after a period of disuse, the battery has not regained its normal voltage, it will not be able to send a sufficient current through the transmitter to properly actuate it; for during the period of disuse the transmitter will have become cold and its resistance therefore correspondingly high. In this case, the battery will probably not be able to send enough current through the transmitter to heat it appreciably, and therefore the resistance of the transmitter will not be lowered. It is thus seen to be of great importance that a battery should possess above all other considerations the power of quickly regaining its strength, or recuperating, as it is termed, after it has been subjected to severe use.

248. Other Requirements.—Besides possessing the proper voltage, low internal resistance, capability of working a reasonable length of time without great falling off in electromotive force and recuperative power, a cell to be suitable for telephone work should possess the following features: It should be cleanly and be free from the production of noxious fumes or gases and the creeping of salts, and the fluid should be of such a nature as to produce a minimum amount of damage when spilled; the electrolyte should be of such a nature as not to freeze at ordinary temperatures, for it is frequently necessary to install telephones in positions where the temperature may fall very low; the cells should be as free as possible from local action, so that while the external circuit is open, there may be no waste of material, which makes the operation of the cell expensive, not only on account of the materials required, but also on account of the frequent visits of an inspector; it should use materials that are inexpensive, and should be of such a nature as to be readily replenished when necessary, and should not require too frequent attention or renewal of solutions or parts.

THE LECLANCHÉ CELL.

249. The cells of the Leclanché type have been found the most desirable for supplying current in the local circuits of telephones, not because they meet all the requirements mentioned, but because they fulfil more of them than probably any other class of cell. They possess to a high degree the recuperative power so desirable, and also have a reasonably high electromotive force, usually about 1.4 volts. The cell used by the Bell Company in connection with the Blake transmitter is almost without exception of the disque or porous-cup Leclanché form described in the Instruction Paper on *Batteries*.

THE HAYDEN CELL.

250. A better form of cell is what is known as the Hayden No. 2, shown in Fig. 98. In this cell, the depolarizer, instead of being contained in a porous cup as in the disque Leclanché cell, is contained within a carbon cylinder, which in itself forms the negative electrode of the battery. The zinc is of substantially cylindrical form and surrounds the carbon cylinder, thus, by virtue of its large surface and the short distance between the two electrodes, producing a very low internal resistance. In Fig. 98, the carbon cylinder *C* is corrugated on its exterior surface, so as to present as large a surface as possible to the electrolyte, and contains the depolarizer *D*, composed of a mixture of manganese dioxide and crushed carbon in about equal portions, each being broken up into particles somewhat smaller than peas. The carbon cylinder *C* engages the cover plate *B*, also of carbon, by means of a screw-thread, as shown. The positive terminal *T* of the cell is composed of the threaded stud *t* and the washer and locking nut *t'* and *t"*. The stud is secured in place by means of molten tin, which is poured into the hole in the cover plate, the plate itself being previously heated to a high degree. After this, the entire cover plate is boiled in paraffin, so as to prevent corrosion between the metallic terminal *T* and the carbon. Unless this or similar means is taken, this corrosion is sure to set in, due to the absorption of the chemicals in the solution by the porous carbon.

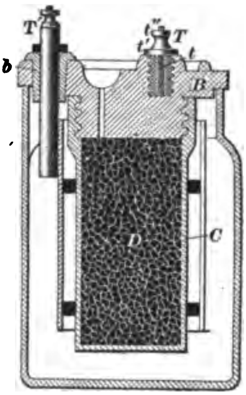


FIG. 98.

Around the carbon cylinder are stretched two heavy rubber bands, the purpose of which is to maintain the zinc cylinder at a proper distance from the carbon. A zinc rod carrying the negative terminal *T'* of the cell passes through a porcelain bushing *b* in the cover plate, it being soldered at its lower end to the zinc cylinder. Much trouble has been experienced in these cells, due to the rapid eating away of the zinc at the point where this rod joined it. This was undoubtedly due in a large measure to the presence of some foreign substance introduced by the solder, and also, to a less extent, to the fact that the action was more violent at that point, owing to the smaller amount of resistance through the cell at that point. This trouble has, however, been entirely overcome by painting the plate and the rod in the vicinity of the joint with some material such as a mixture of pitch and tallow, which adheres strongly to the surface and prevents the action of the electrolyte at this place.

251. Life of Batteries.—Under fair circumstances, a good cell of Leclanché battery should last at least six months, with no other attention than the occasional addition of water to supply the loss by evaporation. This length of time, however, is frequently greatly exceeded, and where the service is not very severe, cells frequently last several years.

252. Renewal of Batteries.—When a cell fails to show the proper voltage, the first step to be taken, if the connections are found to be all right and the zinc in good condition, is to pour out the solution, thoroughly wash off the carbon and the zinc, preferably in hot water, and then fill in with a new solution containing not more than four ounces of good, clean sal ammoniac. If the zinc is badly eaten, it should be replaced with a new one. If the cell then fails to show the proper voltage, the porous cup, if the cell is of the disque form, should be soaked for several hours in hot water, and then replaced. The probabilities are, however, that a new porous cup will be required. If the cell is of the Hayden form, the carbon cylinder should be unscrewed, the depolarizer poured out, and a new mixture of crushed carbon and manganese dioxide filled in. It is a good plan, however, before putting in the new depolarizer, to soak the carbon cup in hot water for a few hours, as this tends to open its pores by dissolving all soluble matter within them.

FULLER CELL.

253. As has been already stated, batteries composed of two or three Fuller cells are commonly used with the solid-back transmitter. This cell has the disadvantage of being very unpleasant to handle, on account of the nature of its solutions, and the further disadvantage of producing very serious damage to whatever it happens to be spilled upon. It has the advantage, however, of being able to produce a high and constant electromotive force (2.1 volts), and of being able to maintain this voltage for a considerable period when acting through a small resistance. The cell used by the American Bell Telephone Company is termed the Standard Fuller Cell, and is the same as that described in the section on *Batteries*. In setting up this cell, the solution is made as follows:

Sodium bichromate...........	6 ounces.
Sulphuric acid	17 ounces.
Soft water....................	56 ounces.

If bichromate of sodium is not obtainable, bichromate of potash may be substituted for it in equal quantities. The former, however, is now largely replacing the latter, although there is very little difference in their action.

254. Mixing the Solution.—Great care should be exercised in mixing this solution that the sulphuric acid be poured very slowly into the water. If the operation is reversed, the sudden formation of steam, due to the heat generated by the union between the acid and the water, is very likely to cause an explosion, throwing acid in all directions and frequently doing much damage. It is well also to mix the solution in an earthenware jar, or, if it be mixed in the glass battery-jar, the latter should be previously placed in a vessel containing cold water, in order to prevent the great heat produced from cracking the jar. After having mixed the solution, the jar should be a little less than half filled with it, and the porous cup put in place. In the bottom of the porous cup should be placed about a teaspoonful of mercury, after which the zinc electrode is put in place and the porous cup filled with water. A tablespoonful of common salt added to the water in the porous cup will hasten the action of the cell.

THE STORAGE-BATTERY.

255. The storage-battery, or accumulator, forms an ideal source of current for telephone work, where the proper means for its charging are at hand. The reasons for its adaptability to this work are: first, its high electromotive force, which is practically constant throughout the entire use of the cell; second, its extremely low internal resistance; and third, its cleanliness. The fumes are disagreeable and destructive unless confined by a layer of oil over the solution. Storage-batteries have not been much used at subscribers' stations because of the trouble in charging them. Several systems have been devised for charging them from a source of current at the central office, during all periods when the line is not in use. This system is a very promising one, and will be described in its proper place.

The storage-battery is now being used almost entirely for generating current for talking and signaling purposes in the central offices of telephone exchanges, and this use will be considered fully when exchange systems are described.

THE DRY BATTERY.

256. Under certain conditions, the dry battery has proven very useful in telephone work, but for general use it has not so far demonstrated its ability to compete with the wet cells already mentioned. For portable telephone instruments, and in similar cases where it is desired to have a very light, small battery, these cells answer the purpose, but their internal resistance is apt to increase enormously as they dry out; they have not the recuperative power nor the constancy, nor are they in any way so reliable as a good Leclanché cell, and are therefore not to be recommended for general telephone work.

TELEPHONY.

(PART 2.)

TELEPHONE SWITCHBOARDS.

CLASSIFICATION OF SYSTEMS.

1. A **telephone exchange** is a combination of a number of telephones with their line circuits and switching devices, whereby any telephone may be connected, through the medium of the line circuits and the switching devices, with any of the other telephones, for the purpose of intercommunication between them.

2. The ordinary form of exchange comprises a central office from which the lines or circuits of the various telephone users, or "subscribers," radiate. These lines terminate at the central office in a more or less complicated switching device known as the switchboard.

3. Telephone System.—The term *telephone system* is used to denote the complete organization of the exchange as a whole, and it refers more to the arrangement of the various pieces of apparatus with respect to their circuits than to the actual construction of the apparatus itself; although this latter feature must, of course, conform with the circuits and arrangement of the parts, in order that each part may properly perform its various functions.

4. Telephone-exchange systems may be divided into three general classes, according to the kind of line circuits

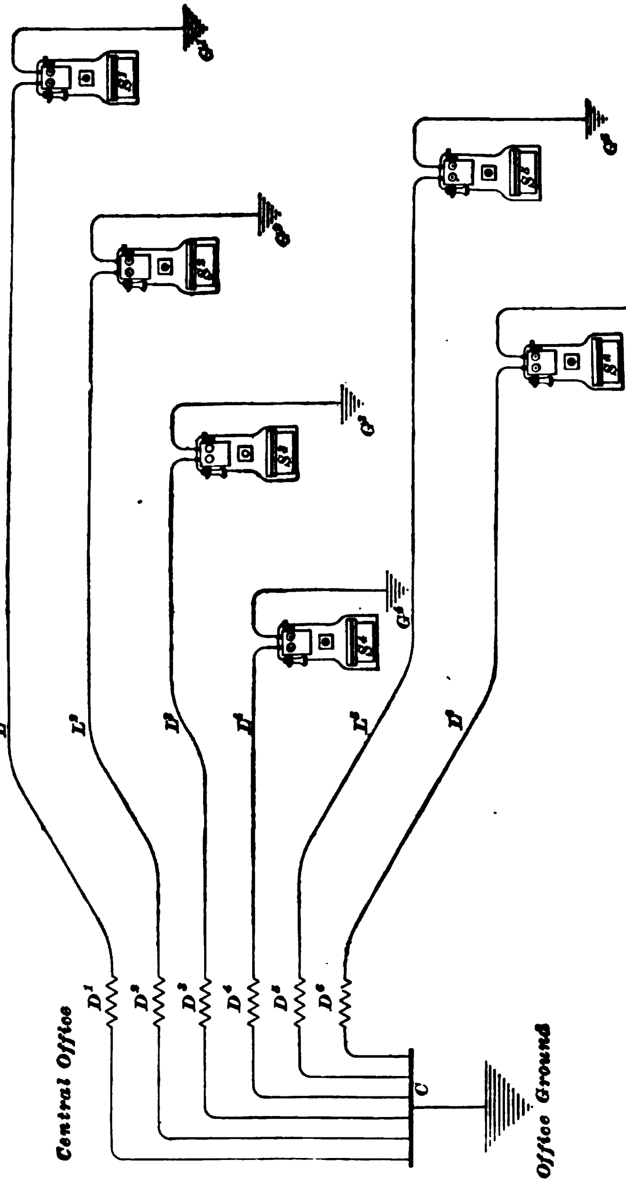

Central Office
Office Ground
C
D1
D2
D3
D4
D5
D6
L1
L2
L3
L4
L5
L6
S1
S2
S3
S4
S5
S6

FIG. 1.

used. There are three kinds of telephone-lines, namely: grounded circuits, common-return circuits, and metallic circuits. We may, therefore, use the same classification in referring to telephone systems, terming them grounded-line systems, common-return systems, and metallic-circuit systems.

GROUNDED-LINE SYSTEMS.

5. Circuits.—In the earliest telephone-lines, the fact discovered by Steinheil, in 1838, that the ground, or, as the English express it, the earth, could be used as a return conductor for completing a circuit between two points, was made use of. Between the two points to be connected for communication was run a single wire, forming one side of a complete circuit, the other side of which was formed by the earth itself in the same manner as is now universally employed in telegraphy.

The arrangement of a group of lines radiating from a central office, using an earth return in the case of each line, is shown in Fig. 1, in which S^1, S^2, S^3, etc., represent the subscribers' stations, at which are placed complete telephone sets, comprising the usual talking and signaling apparatus. Each station is connected by a line-wire L^1, L^2, L^3, etc., with a signal-receiving device D^1, D^2, D^3, etc., usually consisting of some form of electro-mechanical annunciator. The line-wire in each case passes to one terminal of the subscriber's telephone apparatus, the other terminal of which is grounded, as at G^1, G^2, G^3, etc. In a similar manner, the other end of each line-wire is connected to one terminal of its annunciator, the other terminal of which is connected with the ground at the central office. Instead of forming a separate ground for each wire leading from the annunciators at the central office, all these wires may be attached to a common conductor *C*, which is itself grounded at the office.

6. Induction on Grounded Systems. — Systems arranged on this plan are subject to many difficulties which would not be apparent at first sight, but the removal of which, without departing from the system of ground-connections, has so far been found to be impossible. These troubles are due, in the main, to inductive action between other wires and the telephone-wires, and between the telephone-wires themselves. An electric-light wire or any other wire carrying fluctuating currents, running parallel with the telephone-lines, will affect them by induction, causing currents to flow to and fro in them which produce noises in the telephone receivers to such an extent as to often render conversation impossible.

When the induction takes place between two such telephone-lines, the result is that whatever conversation is carried on over one line may be heard on the other, this phenomenon being called cross-talk, and being one of the chief difficulties with which the telephone engineer has had to deal. The fact that induction takes place between two lines is often extremely puzzling to the uninitiated, and frequently leads to the supposition that the two lines may be in contact with each other at some point, or crossed, as it is usually termed. This conclusion, however, is unwarranted, for inductive action is rather facilitated than otherwise by the fact that the two lines are not in actual contact.

7. Leakage.—Another cause for noises heard in telephones connected to grounded lines is due to a form of leakage. Sometimes this is due to a portion of the current flowing in a neighboring wire finding an easy path to the telephone-wire on account of the poor insulation between the two, and then to ground through the telephone instruments, thus causing a noise similar to that produced by induction. A more frequent form of leakage, however, is that from grounded electric-power systems, of which the electric railway is the most usual type. A current from the railway system following the earth return is intercepted by the ground-plate of a telephone station, and thence part of it continues through the ground as before, and another part passes up through the ground-connection of the telephone, through the telephone instruments and line, and again to earth through the ground-connection at the other end. A very slight difference of potential at the terminals of the telephone-line, due to the use of the earth return in electric-railway systems, will cause currents to flow in the telephone-line which will set up the noises already referred to, and often entirely prohibit the use of the telephones on the disturbed lines.

COMMON-RETURN SYSTEMS.

8. Circuits.—As a partial remedy for the difficulties brought about by the grounding of circuits, a system has come into wide use in which a wire common to several or all of the circuits forms the return instead of the earth. This system is generally known as the common-return or McClure system, the latter name being that of its inventor. In Fig. 2 is shown diagrammatically the same group of stations S^1, S^2, S^3, etc., as was shown in Fig. 1, connected by line-wires L^1, L^2, L^3, etc., with the signaling devices D^1, D^2, D^3, etc., in the same manner as in that figure. Instead, however, of using an earth return for these circuits, each line-wire is connected at each end, after passing through the instruments, to a common-return wire which passes from the central office, following, as closely as possible, the same route as the line-wires L^1, L^2, L^3, etc. In order to shorten up the various leads l^1, l^2, l^3, etc., which connect the stations with the common-return wire, the common-return wire may itself be branched so as to pass near to the various stations. In practice, several different common-return wires, all connected together at the exchange, are sent out in various directions from the exchange, following the route in each case of its own group of line-wires as much as possible. It sends off lateral branches wherever necessary to facilitate the work of connecting the various stations to it.

9. Advantages of the Common-Return System.—Inasmuch as a system thus constructed is entirely free

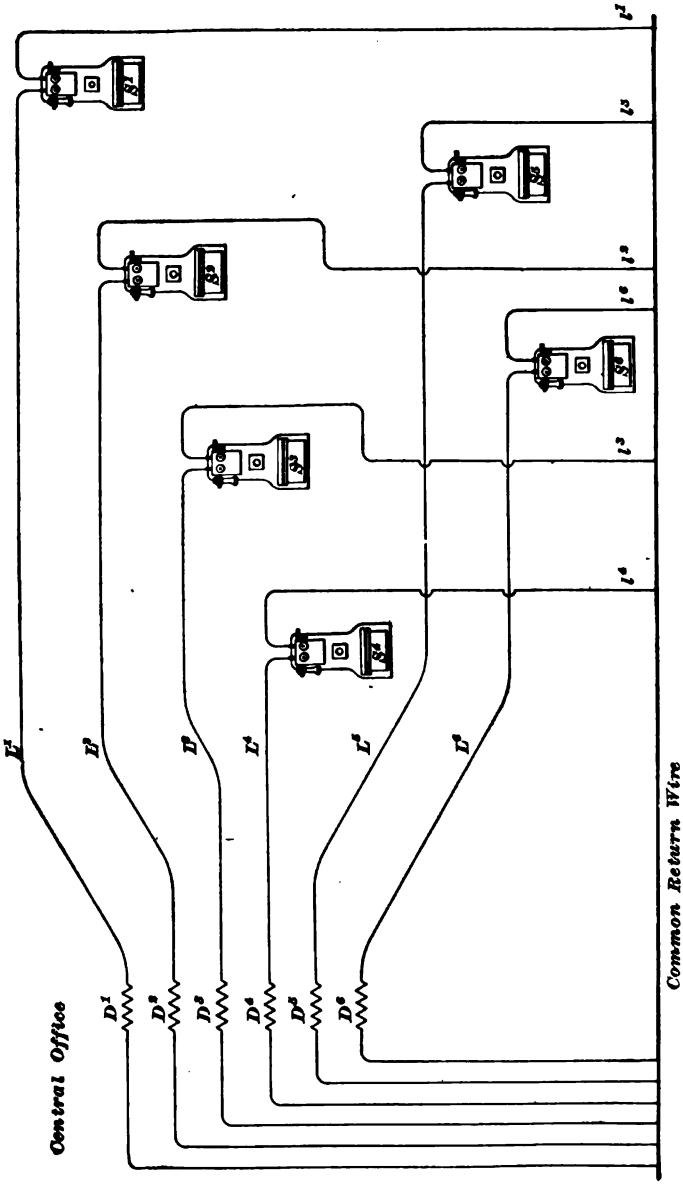

Central Office
D1
D2
D3
D4
D5
D6
E1
E2
E3
L4
L5
L6
S1
S2
S3
S4
S5
S6
l1
l2
l3
l4
l5
l6
Common Return Wire

FIG. 2.

from ground-connections, with the exception of a single ground-connection which is sometimes placed on the common-return wire at the central office, the leakage difficulty is almost entirely done away with. The induction between the various telephone-lines, and also between other lines and the telephone-lines, is greatly reduced, because the common-return wire is acted upon also by the inductive influence, and, as it forms the return side of each circuit, has a tendency to neutralize the inductive action in the lines themselves.

METALLIC-CIRCUIT SYSTEMS.

10. Circuits.—In reality the common-return system just described is one form of metallic-circuit system, because the circuits are completed entirely through metallic conductors. From common usage, however, it has become customary to refer to only those lines that have individual return wires, as metallic circuits. In a metallic-circuit system, therefore, two lines are extended from the central office to each subscriber's station. These lines are of the same size, and placed as far as possible in such manner as to be equally distant from all disturbing sources, such as other wires. The same group of stations S^1, S^2, S^3, etc., is shown in Fig. 3, connected by complete metallic circuits with the central-office signaling devices. Each metallic circuit L^1, L^2, L^3, etc., is composed of two lines of wires l' and l''.

It is sufficient at this point to say that the metallic circuit alone has completely and satisfactorily solved the various problems arising from induction between the telephone-lines themselves, and also from wires carrying other kinds of current. The construction of metallic circuits throughout a system of course involves considerable expense, and where this can not be well afforded, the common-return system may be used, and if properly and carefully designed, is capable in systems of moderate size of giving very satistory service. A grounded-line system should never be used, except in the smallest exchanges, where the lines are short and where there are no electric railways or electric-lighting

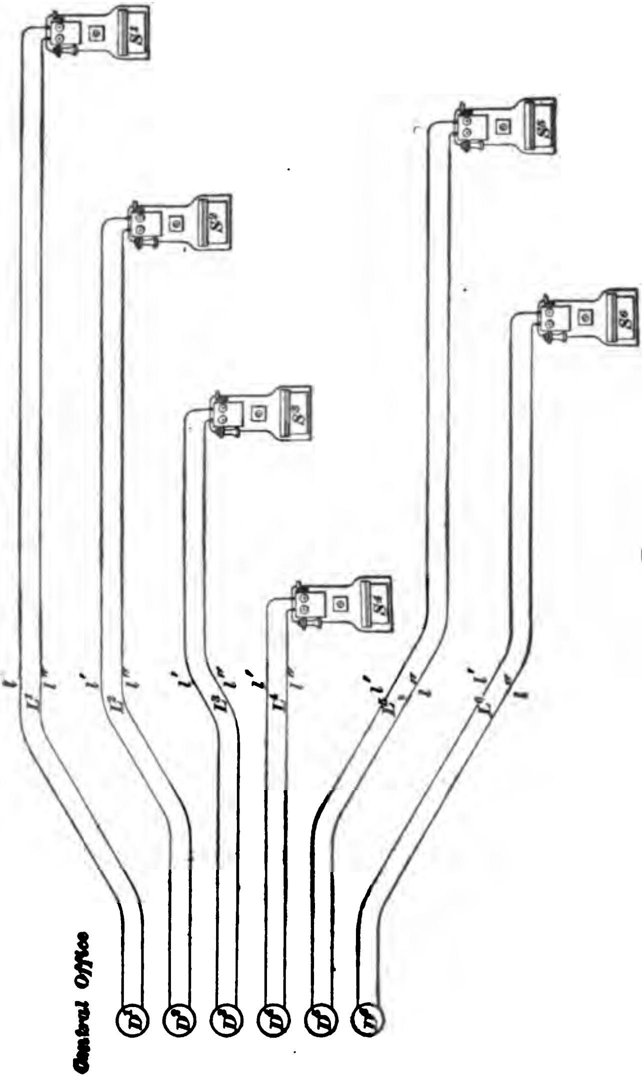


FIG. 2.

systems. The questions governing the design and construction of the line circuits of an exchange will be considered from both practical and theoretical standpoints in *Telephony*, Part 4, it having been thought best to give the student some preliminary ideas of the various types of lines before taking up the question of exchange systems in detail.

CLASSIFICATION OF SWITCHBOARDS.

Switchboards may be divided into two general classes: manual and automatic.

11. Manual Switchboards.—Switchboards of this class comprise those in which the various operations needed to bring about a desired connection or disconnection between any two subscribers are performed manually by operators—usually girls.

12. Automatic Switchboards.—In exchanges using this type of switchboard, the attempt has been made to do away with the central-office operators, reliance being placed upon mechanisms at the central station, adapted to be controlled by the subscribers themselves, in order to bring about the connection or disconnection desired.

Up to the present time, the automatic switchboard has been used only for comparatively small exchanges. Probably a greater proportion than 99 per cent. of the exchanges in the United States, and, in fact, the world over, use manually-operating switchboards for the interconnection of the subscribers.

SWITCHBOARDS FOR SMALL EXCHANGES.

13. General Operation.—In a manually-operated switchboard, apparatus must be provided for attracting the attention of the operator when a subscriber desires a connection, means for enabling the operator to connect her telephone with the line of a calling subscriber in order to receive from him the order for connection, means for connecting his line with the line of the subscriber called for, means for calling up the latter subscriber, and lastly, means enabling either of the two connected subscribers to attract the attention of the operator in order to inform her that the connection is no longer desired, or that they desire their lines connected with those of other subscribers.

14. Call-Receiving Device.—The device by means of which a subscriber is enabled to attract the attention of the operator at the switchboard is usually some form of electro-mechanical annunciator, termed a drop, from the fact that, as ordinarily constructed, a shutter or target is allowed to fall in order to display a signal to the operator. It is released at the proper time by a current passing through its electromagnet when a subscriber operates his signal-sending device. A common form of such an annunciator or drop is shown in Fig. 4, in which *C* is an electromagnet

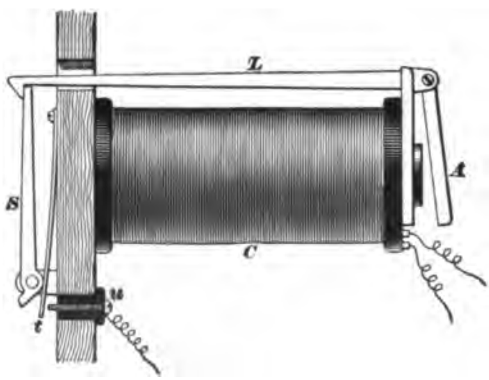


FIG. 4.

mounted behind the front plate of the switchboard. *S* is a shutter pivoted below and normally held in its raised position by a catch on the end of the lever *L*. This lever is rigidly secured to the armature *A* which is pivoted to an upwardly projecting plate from the rear end of the magnet spool, as shown. When a current is sent through the coil *C*, the armature *A* is attracted to the core, lifting the front end of the lever *L*, thus removing the catch from engagement with the shutter and allowing it to fall, and thereby displaying to the operator a designating number, either upon the back face of the shutter *S*, or, what is more usual, upon that portion of the front plate that is normally concealed by the shutter.

15. Night Alarm.—An auxiliary feature known as a night-alarm attachment is shown in connection with this drop. When the shutter falls, the spring *t*, which is made of very thin spring metal so as to be easily bent, is pressed into engagement with the contact pin *u* by the cam projecting from the bottom of the shutter. The spring *t* and contact *u* form the terminals of a circuit containing a battery and an ordinary vibrating bell, and the bell is therefore sounded whenever a drop falls, unless the night alarm is open at some other point by a switch, which is usually the case during the daytime, when an operator is required to be constantly in front of the board, and therefore able to perceive visually the shutters as they fall. This night-alarm arrangement is therefore, as a rule, used only at night, when the exchange is not busy and when one operator is required to serve a larger number of lines than she could during the busy portions of the day.

16. Connecting Devices.—The devices by which the operator is enabled to connect her telephone with the line of a calling subscriber and to subsequently connect that line with some other line consist of switches, termed spring-jacks, and connecting cords terminating in plugs. The spring-jacks are usually in the form of stationary sockets, which contain simple switching devices permanently connected with the subscriber's line circuit to which that jack belongs. The connecting plugs, forming the terminals of flexible cords, are adapted to fit into the spring-jacks and continue the circuit of the corresponding lines to the telephone of the operator or to the line of another subscriber. In Fig. 5, *J* represents the spring-jack and *P* the connecting plug. The jacks are mounted in the rear of the front panel of the board *B*, usually below the line drops shown in Fig. 4. *S* is a flexible spring mounted on the frame of the jack and normally resting against the pin *p*, with which it makes electrical contact. When, however, a plug *P*, consisting of an insulating handle and a forwardly projecting conducting surface, is inserted into the jack from the front of the board, as shown, the spring makes contact with the

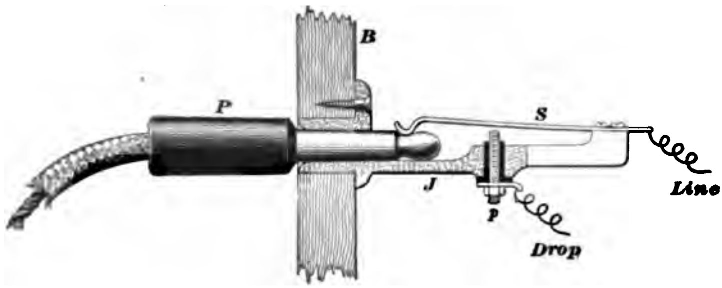


FIG. 5

metallic conducting portion of the plug, and is lifted thereby from contact with the pin *p*. From the rear end of the insulating handle of the plug projects a flexible conducting cord, by which the circuit is continued from the line-wire, through the spring *S* and conducting portion of the plug, to other parts of the apparatus, as will be described.

17. The pin *p* is connected with one terminal of the drop coil, the other terminal of which is grounded or connected with the return wire, and therefore, under normal conditions, when no plug is inserted into the jack, the circuit of the line-wire may be traced through the spring *S*, pin *p*, to and through the coil of the drop, and to ground or the return wire. It is over this circuit that the subscriber sends his calling current, in order to attract the attention of the operator. The jack and plug shown in this figure are for grounded or common-return circuits only, which systems, on account of their simplicity, will be considered first.

SWITCHBOARDS FOR COMMON-RETURN OR GROUNDED LINES.

18. Circuits and Apparatus.—The circuits of one of the simplest possible forms of switchboard are shown in Fig. 6, in which *J*, *J'* are spring-jacks connected with

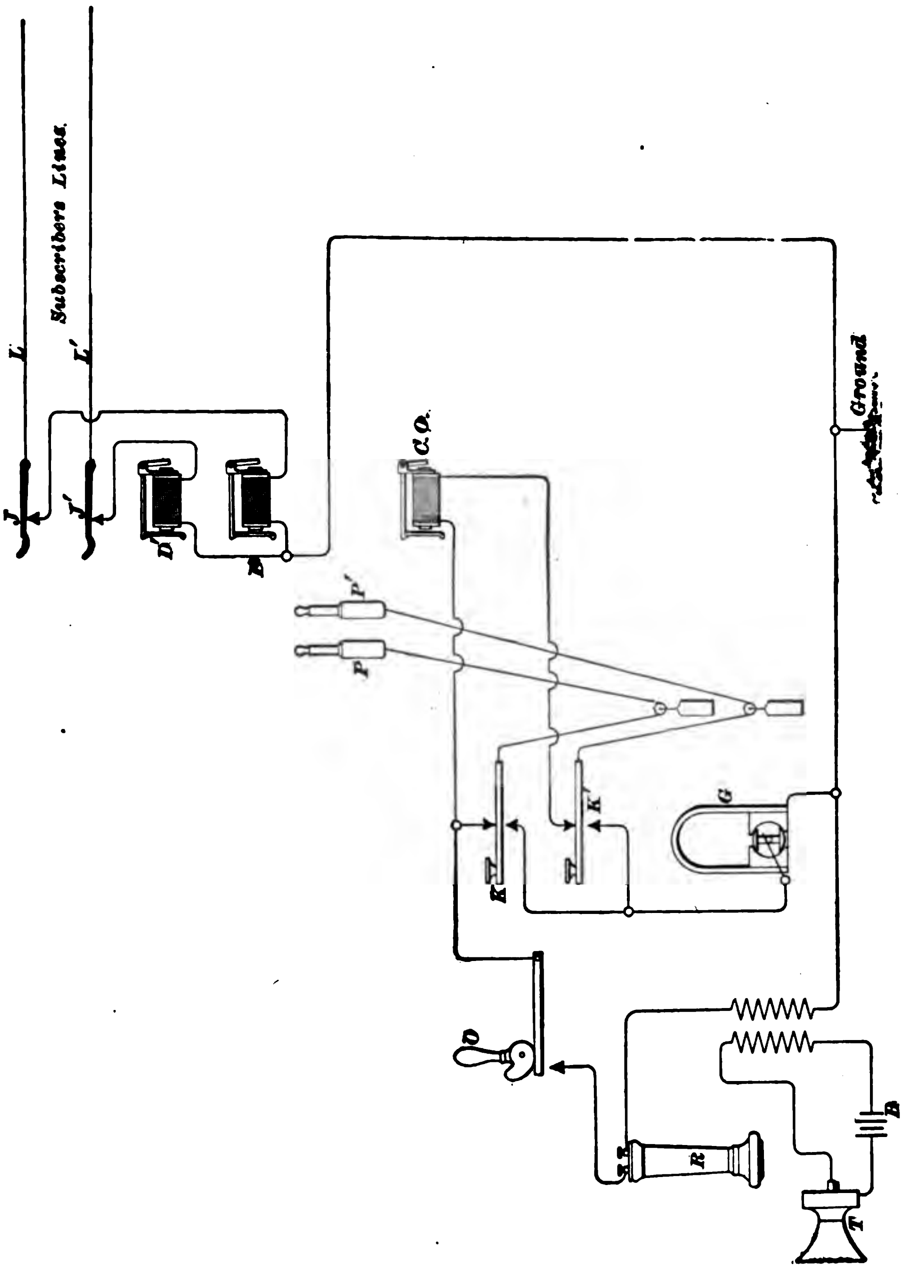


FIG. 6.

subscribers' lines, as shown. The contact pin or anvil on each jack is connected through the magnet of a drop *D* or *D'* to the ground, so that under normal conditions the circuit of the line passes through the drop magnet and to ground; but when a plug is inserted, the connection through the drop is broken by lifting the spring of the jack out of contact with its anvil. *P*, *P'* are the connecting plugs, attached by means of flexible cords to the levers of the keys *K* and *K'*, respectively, which levers are normally pressed against their upper contacts by means of suitable springs, so that the circuit between them is completed through the magnet of an additional drop *C. O.* The two plugs are therefore normally connected together through the drop *C. O.*, but by depressing either of the keys *K* or *K'*, the corresponding plug is cut off from the other plug, and at the same time is connected with one terminal of a magneto-generator *G*, the other terminal of which is grounded. Joined to the upper contact of the key *K* is a lever adapted to be depressed by the cam *O* against a contact forming one terminal of the secondary circuit of the operator's equipment, including her receiver *R* and the secondary of her induction-coil. The other terminal of this circuit is grounded. The primary circuit containing the battery *B* and the operator's transmitter *T* is associated with the secondary circuit in the ordinary manner.

19. Operation.—Suppose now that the subscriber on line *L* sends in a call by operating the generator of his telephone set. The operator will see the shutter of the annunciator *D* fall, and will at once insert the plug *P* into the corresponding jack *J*. She then turns the cam lever *O* into such a position as to press its lever against the contact below, thereby connecting her telephone set between the line *L* and the ground. This circuit may be traced from the line-wire *L*, through plug *P* and its flexible cord, key *K*, listening key *O*, operator's receiver *R*, and secondary winding of the induction-coil to ground. The operator is thus enabled to converse with the calling subscriber, and learning that he wishes, we will say, to converse with the subscriber on the line *L'*, she inserts the plug *P'* into the jack *J'* and presses down on the lever *K'*. This latter movement disconnects the plug *P'* from the drop *C. O.* and the plug *P*, and immediately thereafter connects it with the terminal of the calling generator *G*. This generator is usually constantly driven by an electric motor, or possibly a water-motor, so that a current at once flows from the generator through key *K'*, to plug *P'*, and over line *L'*, through the bell of the called subscriber, thus calling him to his instrument. If the subscriber *L'* acknowledges the operator's call, she restores *O* to its original position, thus cutting out her own telephone set, and key *K'*, being already released, the two subscribers are connected together for conversation through the following circuit: From ground at the station of line *L*, subscriber *L*'s telephone, line *L*, spring-jack *J*, plug *P*, flexible cord, key *K*, drop *C. O.*, key *K'*, flexible cord, plug *P'*, jack *J'*, line *L'*, and through the instrument at the end of line *L'* to ground.

20. It will be noticed that the drop *C. O.* is included in this circuit connecting the two subscribers. This is called the clearing-out drop, and its function, as its name implies, is to convey a signal to the operator when either subscriber operates his generator, after conversation, to signify that a disconnection is desired, or that the subscribers wish their lines connected to other subscribers. When the shutter of this drop falls, the operator therefore again listens into the circuit by operating the key lever *O*, and if she obtains no response from either party, concludes that the signal was for disconnection, and removes both plugs *P* and *P'* from the jacks. It will be noticed that when the operator listens in upon the circuit of two connected subscribers, her telephone is contained in a derived circuit branching from the circuit connecting the two subscribers to the ground. The current from the telephone of that subscriber who happens to be talking at any instant divides between the operator's and the other subscriber's telephone.

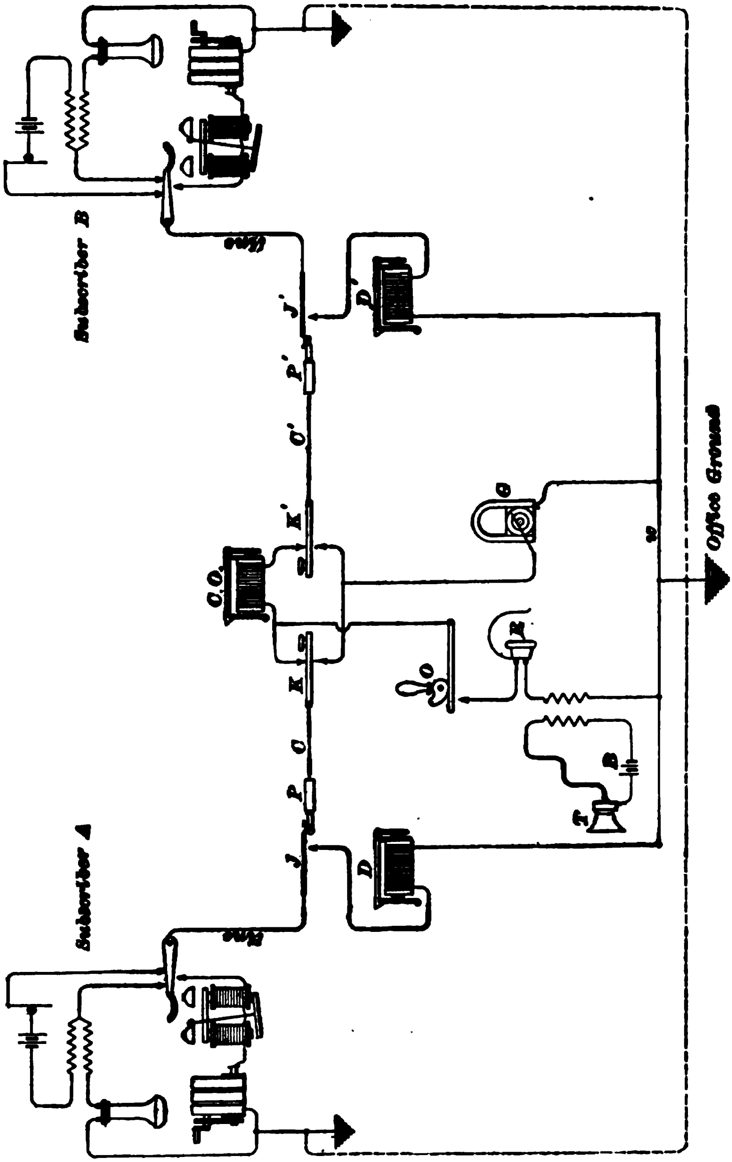

Subscriber B
Line
J'
D'
P'
C'
K'
G
C.O.
w
Office Ground
R
K
O
C
B
P
T
J
D
Line
Subscriber A

FIG. 7.

21. In Fig. 7 are shown the same circuits as those indicated in Fig. 6, but this figure is made to include also the circuits of two subscribers' stations, connected for conversation through the switchboard. The jacks *J* and *J'* and their corresponding drops *D* and *D'* are shown removed from each other as though on separate boards; but this is done for the sake of clearness in diagrammatical illustration, and this system will be followed largely throughout the remaining portion of this work. For further clearness, the flexible cords *C*, *C'* in this figure, connecting the plugs *P* and *P'* with the keys *K* and *K'* respectively, are represented by a straight line; the pulley weight used in connection with each cord, for the purpose of keeping it taut, is also omitted. In this figure also a watch-case receiver *R* is shown in place of the ordinary hand-receiver, as in Fig. 6, this form of receiver being found most desirable on account of its light weight and shape for operators' use, and is employed in nearly every central exchange.

22. Ground Connections.—It will be noticed that all the circuits at the central office which are connected with the ground are connected first with a common wire *w*, which is itself grounded at what is termed the office ground. Each subscriber's instrument is also connected with the ground, as shown, and in this ground branch is normally included the magneto-generator and call-bell, while the receiver is on its hook. When, however, the receiver is removed from its hook, the circuit is broken through the calling apparatus, but established through the talking apparatus, including the subscriber's receiver and the secondary winding of his induction-coil. These circuits will be seen to be the same as those already described in connection with complete telephone instruments.

23. Ground on Common Return.—When a common-return wire is used instead of ground, the connection is made as shown by the heavy dotted line in Fig. 7; the ground at the subscriber's station being then omitted, except for the purpose of obtaining a ground for the lightning-arrester. Many exchange managers seem to prefer to ground the common-return wire at the central office, and, on the other hand, many equally competent managers prefer to keep the common-return wire free from grounds throughout the entire system. In some cases, undoubtedly, one plan might prove more desirable than the other, and as the experiment is easily tried, the proper method to suit any case can best be determined by actual trial.

SWITCHBOARDS FOR METALLIC-CIRCUIT LINES.

24. The form of switchboard so far described is suitable for either grounded or common-return lines. A switchboard to accommodate metallic-circuit lines is, however, of necessity of a somewhat different construction, because connections must be provided for two wires for each line circuit, and also means for continuing the circuit from these two wires through the switchboard, in order to connect them with the two wires of another line. The signal-receiving device need not be different from that of the common-return or grounded line board, although the method of connecting it with the circuits is different. The jack and plug, however, must be radically different, as each must be provided with two contacts instead of one; the two contacts in the jack forming, respectively, the terminals of the two sides of the line circuit, and the two contacts on the plug adapted to connect with the jack contacts when the plug is inserted. Each contact on a plug is normally connected to a similar contact on the companion plug through the means of a double-conductor flexible cord. The arrangement of the operator's talking circuits and also of the circuits of the calling apparatus follow the same general plan as that of the grounded-circuit system, but instead of connecting these various circuits between the single-cord conductor and the ground or common return, they are connected between the two conductors of the flexible cord.

25. Jack and Plug.—In Fig. 8 is shown a spring-jack arranged for metallic circuits, and also a double-contact plug, the two metallic portions of which are adapted to engage the contacts in the spring-jack. In this jack, *s* is the metallic framework upon which the various parts are mounted. Carried upon, but insulated from, this framework is the pin *p*, to which is attached a metallic strip *c*, which is of sufficient length to project a slight distance from the rear of the jack. Mounted also upon the frame is the spring *t*, which is insulated from the frame, but adapted to normally rest upon the pin *p*. This spring *t* also has a rearward projection similar to that on the strip *c*. One side of the line circuit is connected with the metallic frame *s* by

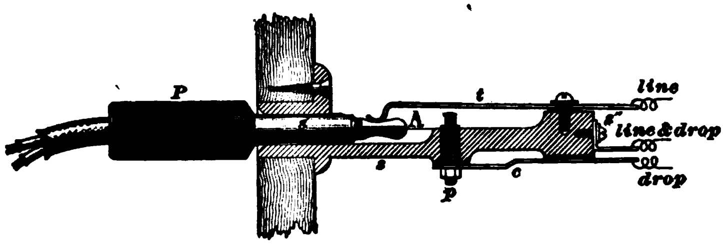


FIG. 8.

means of the screw *s'*. The other terminal of the line is connected with the rear projection on the spring *t*, while the projection on the strip *c* is connected with one terminal of the winding of the line drop, the other terminal of which is connected to the frame of the jack at *s'*. The plug *P* has an insulating handle and two metallic contacts *A* and *s'*, to each of which are connected on the interior of the insulated handle a terminal of one of the conductors of the flexible cord. The contact *A* is termed the tip, while the contact *s'* is termed the sleeve of the plug, the latter surrounding the former, but carefully insulated from it by means of a tubular bushing of hard rubber or similar material. The conductor of the cord circuit which makes contact with the tip of the plug is usually designated as the tip strand of the cord, and likewise the conductor making contact with the sleeve of the plug is termed the sleeve strand. For similar reasons, the contact spring *t* in the jack is termed the tip spring, while the contact *s* with which the sleeve of the plug

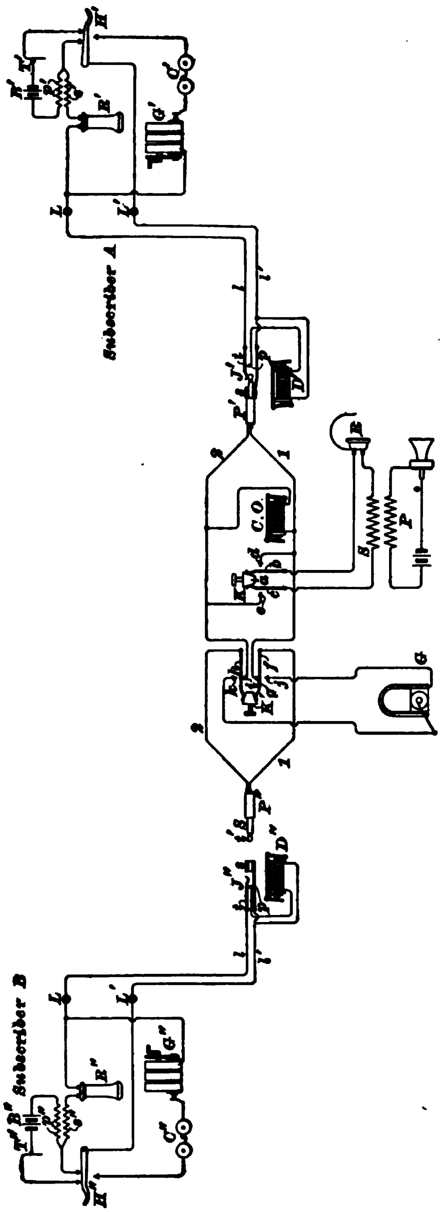


FIG. 9.

engages, in this case the metallic frame of the jack itself, is called the sleeve contact, and the two sides of the line are frequently termed, in small exchanges, the tip and sleeve conductors, respectively.

26. "Line" and "Test." — Another way of designating the two conductors of the line circuit and their respective contacts is to speak of that conductor which is connected with the spring *t* as the "line," while the other side is termed the "test." The reason for this designation will be understood when multiple boards are discussed, but for the present the terms "tip" and "sleeve" will be adhered to. When the plug is inserted into the jack, its tip makes contact with the spring *t* and raises it from engagement with the pin *p*, thus breaking the circuit through the line drop, as in the case of the grounded-line jack.

27. The Line Circuit.—The circuits of a simple metallic-circuit exchange are represented in Fig. 9. In the metallic circuit, jacks *J'* and *J''* are shown, the sleeve conductor *s* corresponding to the frame *s* in Fig. 8, the tip spring *t* and the anvil *p* both being lettered the same as the corresponding parts in the jack shown in the same figure. The line conductors *l* and *l'* are connected, respectively, with the tip and sleeve contacts, while the drop *D'* and *D''* are in each case connected between the anvil *p* and the sleeve side of the line. It will be seen that under normal conditions, as shown at *J''*, the drop is connected between the tip and sleeve sides of the line *l* and *l'*, respectively. The circuit, therefore, of a calling current coming in from a subscriber *A*, when there is no plug inserted in the jack *J'*, may be traced from the tip side *l* of the line to the tip spring *t*, anvil *p*, coil of the drop *D'*, belonging to *A*'s line, and to the opposite side *l'* of the line.

28. The Cord Circuit.—*P'* and *P''* are termed, respectively, the answering and calling plugs, because *P'* is used to answer an original call and *P''* for calling the subscriber wanted. The tips of the two plugs are connected together through the tip strands *1* of the flexible cords, while the sleeves are similarly connected by the sleeve strands *2* of the same cords. The clearing-out drop *C. O.* is permanently bridged across the tip and sleeve strands of the cord of the answering plug. In order that this drop shall not form a circuit of too low resistance between the two sides of the circuit connecting two subscribers together, the magnet of the drop is wound to have a high resistance, from 500 to 1,000 ohms. The impedance of the drop is still further increased by enclosing the entire winding in a tube of soft annealed iron, which tube forms the return portion of the magnetic circuit of the core, furnishing a path of low magnetic resistance, or reluctance, as it is called, for the lines of force, and, therefore, with a given iron core, a given number of turns in the coil, and a given current, the total number of lines of force, and consequently the coefficient of self-induction, will be a maximum.

From the formula

$$\text{Impedance} = \sqrt{R^2 + (2\,\pi\,n\,L)^2},$$

it is evident that the impedance will be much larger than the simple resistance R when both the coefficient of self-induction L and the frequency n are large, as they will be with this tubular form of drop during a conversation. While talking, the average value of n is about 300, but for the current from a telephone generator it is only about 14. The impedance of the drop is therefore much larger for the talking than for the generator current, and consequently sufficient of this latter current will flow through it to drop the shutter, but practically the whole talking current will be prevented from passing through it.

29. Ringing and Listening Keys.—A key K when depressed will connect the secondary circuit of the operator's telephone set across the two strands of the answering plug P', the action of this key being as follows: The conical wedge a, when pressed down by the button, presses the two springs b and c, which form the terminals of the secondary of the operator's circuit, against the two stationary anvils d and e, which are connected, respectively, with the two strands of the answering cord.

K' is the ringing key, by which the operator may connect the terminals of the calling generator G with the two strands of the cord of the calling plug P''. Normally the tip strand *1* of the calling plug is connected with that of the answering plug by means of the spring f resting against the anvil g of the ringing key, and in a similar manner, the circuit between the sleeve strands *2* of the pair of plugs is maintained continuous by the spring h resting against the anvil i. When the key K' is pressed, however, the springs f and h are forced out of engagement with the anvils g and i and are pressed against the contact anvils j and k

forming the terminals of the generator *G*. Thus, the operation of the key *K'* disconnects the calling plug *P"* from the answering plug *P'*, and at the same time connects the calling plug with the terminals of the generator *G*.

30. Calling Central.—In Fig. 9 the circuits are shown corresponding to the position of the apparatus when the operator has inserted the answering plug *P'* into the jack *J'* of a calling subscriber, for the purpose of ascertaining his wants. The subscriber *A*, for the purpose of sending a call, operated his generator and caused his drop *D'* at the central office to display its signal. The operator, in answer to this signal, has inserted the answering plug *P'* into the jack *J'*, thereby continuing the circuit of the subscriber's line to the cord circuit, and at the same time cutting out the drop *D'* by virtue of the lifting of the spring *t* from the anvil *p*. It is in this position that the apparatus is shown.

31. Listening In.—The next step on the part of the operator is to depress the key *K*, thereby forcing the springs *b* and *c* into engagement with the anvils *d* and *e*, and bridging her secondary circuit containing the head receiver *R* and the secondary *S* of the induction-coil across the cord circuit. She is enabled to converse with the calling subscriber in the ordinary manner, the circuit over which this conversation takes place being traced as follows: secondary winding *S* of the operator's induction-coil, spring *c* of the operator's key, anvil *e*, sleeve strand *2*, sleeve of plug *P'*, line-wire *l'*, binding-post *L'* of the telephone at station *A*, lever *H'* of the hook switch, secondary coil *s'*, subscriber's receiver *R'*, binding-post *L*, at station *A*, line-wire *l*, tip spring *t* of the jack, tip of plug *P'*, tip strand *1* of the cord, anvil *d* of the operator's key, spring *b*, operator's receiver *R*, and back to the secondary *S*. This circuit is acted upon by the operator's transmitter through her primary coil *P*, in the ordinary manner.

32. Making Connection.—Having learned that the subscriber *A* desires to be connected with subscriber *B*, the operator inserts the calling plug *P"* into the jack *J"* of subscriber *B*, thus cutting out his line drop *D*″ and establishing connection with his line-wires *l*, *l*′. She then depresses the ringing key *K*′, which connects the generator *G* directly across strands *1* and *2* of the calling cord, thus ringing the bell *C*″ at the station of subscriber *B*. This calling current from the generator *G* does not pass to the station of the subscriber *A*, because in its action the key *K*′ disconnected the plug *P*′ from the rest of the circuit by breaking the contacts *h*, *i* and *f*, *g*. It is not desirable to send the calling current from the switchboard generator to the station of the subscriber calling, because he is holding his receiver to his ear, and the generator current, in passing through it, will produce a violent noise, sometimes very painful to the ear-drum, and always annoying. For this reason, in good switchboards provision is made whereby the answering plug is cut off when the calling generator is connected with the calling plug.

33. Talking Circuit.—When subscriber *B* removes his receiver from its hook, the talking circuit between the two subscribers is complete, and may be traced as follows: secondary *s*″ of the induction-coil at the station of subscriber *B*, receiver *R*″ at the same station, binding-post *L*, line-wire *l*, tip spring *t* of jack *J*″, tip *t*′ of the plug *P*″, tip strand *1* of the calling cord, spring *f*, anvil *g*, tip strand *1* of the answering plug, tip of plug *P*′, tip spring *t* of jack *J*′, line *l* of subscriber *A*, binding-post *L*, receiver *R*′, secondary *s*′, hook lever *H*′, binding-post *L*′, line *l*′, sleeve *s* of jack *J*′ and of the answering plug *P*′, sleeve strand *2* of answering plug, anvil *i*, spring *h*, sleeve strand *2* of calling plug, sleeve *S* of calling plug, sleeve *s* of jack *J*″, subscriber *B*'s line *l*′, binding-post *L*′, hook lever *H*″, and back to the secondary *s*″ of his induction-coil.

34. Clearing Out.—After the conversation is completed, one or both of the subscribers should operate their generators, or ring off, as it is usually termed. This will send a generator current over the line of the two connected subscribers, a part of which current will find a circuit through the clearing-out drop *C. O.*, and cause its shutter to fall. The operator, seeing the signal, should again depress the key *K* and inquire if the subscribers are through talking; if she receives no response, she will disconnect the lines by removing the plugs. If, however, one of the subscribers desires to be connected with still another subscriber, the operator may receive his orders as before, and complete the connection desired.

SWITCHBOARD DETAILS.

35. The two switchboards described in Arts. **18** to **34**, inclusive, are typical of a large number in actual use in the United States. They are never adapted, without certain important modifications, to exchanges having more than four or five hundred subscribers. Before describing the systems for handling a larger number of subscribers, the various parts of switchboards will be discussed, together with principles of their design. The switchboards for handling a larger number of subscribers than that mentioned are as a rule composed of the same parts, arranged, however, in somewhat different circuits from those described.

SWITCHBOARD DROPS.

36. General Requirements.—Of switchboard drops, several important requirements must be taken into consideration. The drop must be so constructed mechanically as to always operate with certainty, even when the magnet is acted upon by very feeble currents. In other words, the mechanical arrangements must be so designed that the shutter will be released by the least possible amount of energy imparted to the armature. The electrical design is no less important than the mechanical, and the point of greatest importance is the prevention, so far as possible, of the liability to short circuits or open circuits between the various convolutions of the winding of the core or framework of the switchboard, and also the prevention of open circuits due to the breakage of the wires. In order that the armature may be acted upon to the fullest extent by the magnetism of the core, the magnetic circuit should, if possible, be so arranged as to present both poles of the magnet to the armature, so that the magnetic circuit will be practically closed by the armature when it is drawn towards the poles. The armature should come as near as possible to the poles without touching them, and it is necessary to construct the core, the armature, and all portions of the magnetic circuit of the best grade of soft iron, so that there will not be enough residual magnetism to cause the armature to stick to the pole-pieces after the current ceases to flow in the coil.

It is usually important, especially in the larger exchanges, to economize space, in order that the requisite number of drops and jacks may be placed in front and within reach of an operator. For this reason the drops must be made small and mounted upon the board with as little space between them as the mechanical and electrical conditions will allow. Each drop should, moreover, be readily accessible at all times, and be so secured to the board that it can be removed, in case of a breakdown, without disturbing the operation of the other portions of the apparatus.

37. Cross-Talk Between Drops.—The mounting of a number of drops in close proximity to each other introduces serious difficulty, which manifests itself in the form of cross-talk. This is true only in the case of drops which are included in the circuit of the line during conversation, as in the case of the clearing-out drops, and also in switchboards where the line drop is left in circuit for any purposes whatsoever. This is due to the induction between the coils of adjacent drops. For instance, when voice currents are passing over one line and through the drop in the circuit of that line, the coil of that drop acts in the same manner as the primary winding of an induction-coil, setting up a varying field of force, which field reaches out so as to include the coils of the adjacent drops. Currents are therefore induced in these coils which vary in unison with the currents in the coil of the first drop, and therefore conversation may be overheard on the lines having drops within the field of force of the first drop.

38. Remedies for Cross-Talk.—Three remedies may be suggested for the removal of this trouble: (1) the drop may be cut out of the circuit during conversation; (2) the drops, if left in circuit, may be placed so far apart as to not affect each other; and (3) the magnetic circuit of the drop may be so arranged as to confine all the lines of force set up by the magnet within itself. The first of these remedies is possible only in the case of line drops, as the clearing-out drops must necessarily be left in circuit during conversation. They are usually of high impedance, and connected across the circuit and not in series with the line. Moreover, it has been advantageous in many cases to leave the line drop in the circuit. The second remedy is usually not feasible, because of the lack of room on the switchboard. The third remedy is the one which is usually resorted to, and which, if properly carried out, gives excellent results. It involves the placing of the coil of the drop completely within a shell of soft iron, which forms in itself a portion of the path of the magnetic lines. The lines of force issuing from the core return through the soft-iron shell to their starting-point, in preference to straying out and returning through the surrounding region.

39. Illustration of Cross-Talk Between Drops.—In Fig. 10, A and A' represent the magnets of two switch-

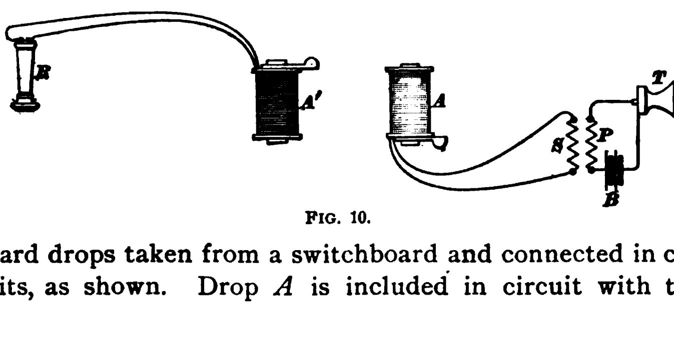


FIG. 10.

board drops taken from a switchboard and connected in circuits, as shown. Drop A is included in circuit with the secondary S of an induction-coil, the primary P of which is connected in circuit with the transmitter T and the battery B. Drop A', which is entirely separated from drop A, is included in circuit with a receiver R. The transmitter and induction-coil should be at such a distance from the two drops and the receiver as to render it impossible for the sounds uttered before the transmitter to be heard through the air at the point where the drops and receiver are located. If a person holds the receiver to his ear and moves the two drops A and A' with respect to each other, he will find that in certain positions he will hear the sounds uttered before the transmitter very distinctly, even though the two drop coils are removed from each other by a distance of several inches. With an ordinary electromagnet, such as is shown in the drop illustrated in Fig. 4, it is often possible to hear these sounds in the receiver when the two drops are as much as a foot apart; while if the two drops be moved together, as they would be when in position on a switchboard, the sounds are so distinct that a conversation can be carried on without trouble.

40. It is probably the claim of all manufacturers that no cross-talk can exist between their switchboard drops. If the drops are cut out of line by the insertion of the plug, no further precautions need be taken in this respect on the part of a purchaser, but if the drop is left in circuit at all times, it is well to investigate this matter thoroughly. The test may be made by the method illustrated in Fig. 10, and great care should be taken that the conditions are the same as those which actually exist in the switchboard; and it is therefore well to make the test while the drops are actually in place on the switchboard. Unless drops are of the iron-clad type or are cut out of circuit, it is safe to say that cross-talk will exist to a more or less serious extent between them.

41. Mechanical Considerations.—From the statements in Arts. **36** and **37** concerning the requirements of a drop, it will be evident that only the best possible mechanical construction can be used with success; and too much can not be said against flimsily constructed drops which are, and have long been, put on the market by some manufacturing concerns. In this connection, it may be said that the experience of the American Bell Telephone Company has proven that in the construction of switchboard drops, as, in fact, in all other classes of telephone apparatus, the best construction is none too good. Several of the independent manufacturing companies have learned this also, and are placing apparatus on the market that is capable of giving thoroughly satisfactory results.

42. In order to reduce the effort needed on the part of the armature in releasing the shutter, it is important that the catch which normally holds the shutter in position shall support the shutter in a position where it has but a *slight* tendency to fall. This may be illustrated by reference to Fig. 4. It will be seen in that figure that the shutter, when in its raised position, is very nearly balanced upon its pivots, so that it exerts but a very slight tendency to fall, and therefore exerts but a small pull upon the catch of the lever *L*. This insures a minimum amount of friction between the catch and the shutter, which, therefore, reduces the pull required by the armature *A* to disengage the catch. In some forms, the movement of the catch in disengaging the shutter is in such a direction as to slightly raise the shutter against its weight before it can release it. This is a minor objection in some cases, but nevertheless one that should be avoided in designing a drop to attain a maximum degree of sensitiveness.

COMMERCIAL FORMS OF SWITCHBOARD DROPS.

43. The drop shown in Fig. 4 is typical of a large class of switchboard annunciators. These are capable of giving good results when properly designed with respect to the mechanical and electrical conditions already pointed out. One objection to the drop shown in that figure is that it has no means of adjustment, and therefore no means of adapting it to long or short lines, or to weak or strong generators. Another objection is that the coil and the shutter are separately mounted on the panel of the switchboard. This panel is usually of wood, and therefore subject to changes in shape due to the absorption of moisture and also to the effects of heat and cold. This results in the alteration of the adjustment of the drop and frequently causes it to become inoperative. A good switchboard drop should have all its parts rigidly mounted upon the same framework, and this framework should be of a material not affected by atmospheric changes.

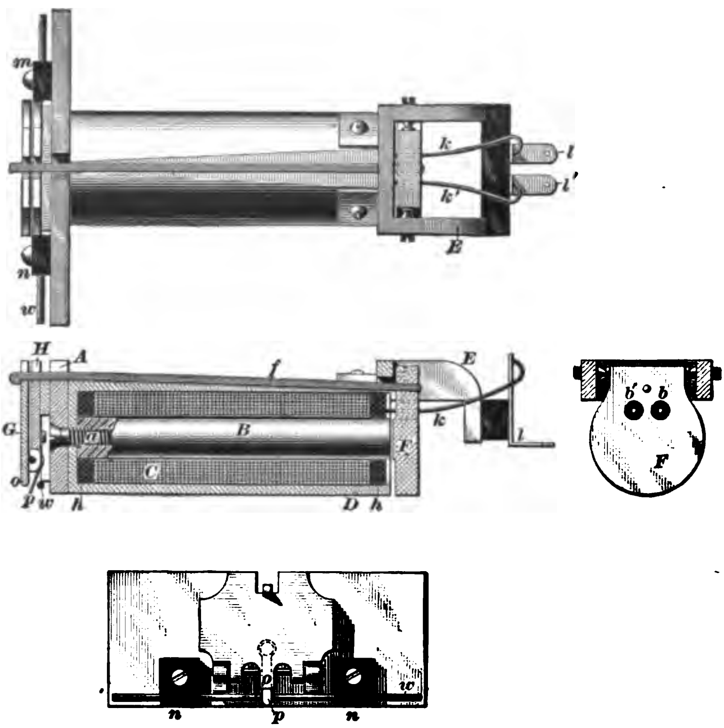


FIG. 11.

44. Warner Tubular Drop.—In Fig. 11 is shown one of the most satisfactory switchboard drops yet devised. This drop, or slight modifications of it, is used in nearly all the American Bell Telephone Company's exchanges where electro-mechanical annunciators are employed. It is manufactured by the Western Electric Company, of Chicago, who make all switchboards for the above named company. The coil *C* of the electromagnet is wound upon a spool composed of a soft-iron core *B*, properly insulated with paper, upon the ends of which are forced two hard-rubber heads *h*. The coil is wound to have a resistance of about 500 ohms, No. 36 or No. 38 B. & S., single silk-covered wire being used. The coil, after being wound, is mounted within a tubular shell *D*, composed of the finest quality of soft iron obtainable. This shell is closed at its forward, and open at its rear, end, it being formed from a single piece of soft-iron rod bored out to the proper depth. This method of constructing it is much more expensive than it would be were the shell formed of a soft-iron tube having a thin cylindrical head driven in at one end; but the manufacturers have found that better mechanical and electrical results were obtained by the more expensive method, and have therefore adhered to it. This point is mentioned as illustrating the high-grade construction that is used in the best types of telephone apparatus. The tubular shell *D* is held against the front plate or panel *A* of the switchboard by means of a screw *a* passing through the forward end of the shell and into the core *B*, the screw thus serving not only to hold the shell against the front plate, but also to bind the core in its proper position within the shell.

45. Upon the rear portion of the shell is secured a bracket *E* of brass, within which is pivoted the soft-iron armature *F* carrying the forwardly projecting arm *f*. This armature, when attracted by the magnet, closes the tube, and therefore completes the circuit of the magnetic lines set up by currents flowing within the coil. It will be seen that both poles of this magnet are presented to the armature, one pole being the end of the core itself, and the other, the end of the shell which forms the outer path for the lines of force. Upon the front of the plate *A* is mounted a plate *H*, on which is pivoted the shutter *G*. A catch on the forward end of the arm *f*, which passes through a notch in the plate *A*, serves to retain the shutter in its raised position. The plate *A* is of iron and in the form of a strip, upon which a desired number of drops are mounted, all the drops in one row being secured to the switchboard frame by means of the plate *A*, which is secured thereto at each end.

46. The terminals *k* and *k'*, leading from the coil within the shell, pass out through holes *b*, *b'* in the armature and terminate in clips *l* and *l'*, mounted upon the rear portion of the bracket *E*. In some cases, however, the extensions on the bracket *E* are omitted, the terminals being formed by means of stiff brass wires of about No. 16 gauge secured rigidly within the rear head *h* of the coil and projecting out for a distance of about ½ inch beyond the rear face of the armature. The terminal wires from the coil are secured directly to these stiff brass wires, which in themselves form the terminals of the coil. In some cases, a night-alarm attachment is placed on these drops. The wire *w*, mounted upon the insulating blocks *n*, forms one terminal of the night-alarm circuit, and is common to all the drops mounted upon one of the front strips *A*. The other terminal of the night alarm is formed by the spring *p*, mounted directly behind the shutter upon the plate *H*, which forms the other terminal of the night-alarm circuit. When a shutter falls, a downwardly projecting lug *o* carried on the shutter presses the spring *p* into engagement with the wire *w*, thus completing the night-alarm circuit in the same manner as described in connection with the drop shown in Fig. 4.

47. Complete Magnetic Circuit.—Many valuable points concerning the construction of drops may be gained by a consideration of the details of the one just described The completeness of the magnetic circuit through the iron of the core, shell, and armature insures not only a maximum pull on the armature by the magnet, but also serves to confine all the magnetic lines set up in the coil within the iron itself, without allowing them to pass out into the surrounding air to any appreciable extent. By thus destroying the external field which is ordinarily present in the air surrounding an electromagnet, the drop is rendered entirely free from any inductive troubles, such as have already been mentioned. So completely has this trouble been removed that under the most favorable conditions for induction, that is, when two drops are in actual contact side by side, no cross-talk or magnetic disturbance of any kind can be noticed between them.

48. High Self-Induction.—Moreover, by the presence of so much iron properly disposed in the magnetic circuit, the drop is given a very high coefficient of self-induction. While the actual resistance of the drop to steady currents is, as has been said, about 1,000 ohms, its apparent resistance or impedance to rapidly alternating currents is several thousand ohms; and as a result, when such a drop is placed in a bridged circuit between the two sides of a telephone circuit, there is no appreciable loss of efficiency in the telephone transmission due to the leakage through the drop.

49. Mechanical Advantages.—The adjustment of this drop can not be affected by any atmospheric changes, because all the parts are rigidly mounted together, all the material connecting them being formed of iron or brass.

The lever *f* is attached to the armature *F* slightly below the pivotal points, in order that when the armature is moved towards the core the catch on the forward end of the rod *f* will be given a slight forward motion, at the same time that it is lifted, in such manner as to assist in disengaging itself from the shutter. The shutter itself, when raised, is in a position to exert but slight pressure upon the catch on the rod *f*, and thus exerts a minimum amount of friction against the catch. All these points serve to make this one of the most efficient drops, in all respects, that has so far been devised.

50. Western Telephone Construction Company's Drop.—In Fig. 12 is shown a drop of the same general type as the Warner, used by the Western Telephone Construction Company. Here the electromagnet and the enclosing tube or shell are exactly the same as those of the Warner drop, being, in fact, made according to the same dimensions. At the forward end of the magnet, the armature *F* is pivoted at two points *e* in a brass bracket *E* having two forwardly extending arms, between which the armature is hung. The shutter is pivoted at *g* between the same arms. In the

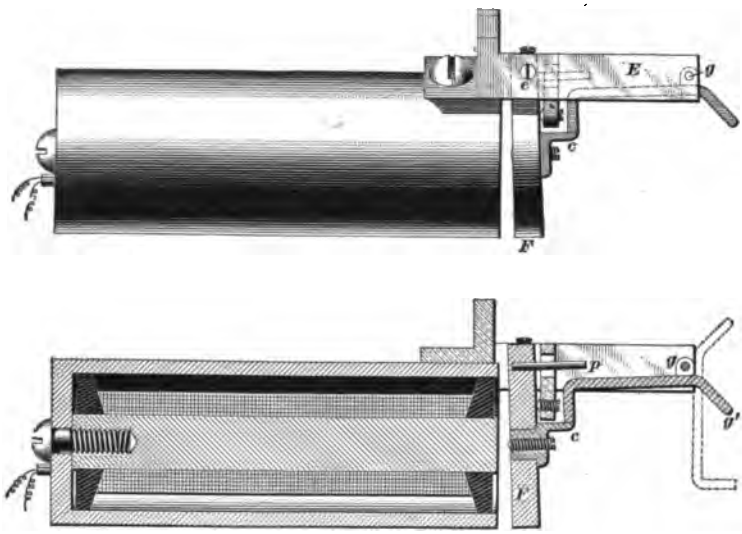


FIG. 12.

center of the armature is carried a small steel catch *c*, upon which the shutter rests when in its raised position. When the armature is drawn towards the magnet, the catch is pulled from under the shutter, allowing it to swing forwards and downwards into the position shown by the dotted lines. Owing to the fact that there is but little tendency for the armature to fall away from the magnet after having been attracted, considerable trouble was experienced, due to its sticking, no matter how soft a grade of iron was used in the construction of the cores. This was overcome by the insertion of the pin p into the upper portions of the armature, in the manner shown. When the shutter is restored by a downward pressure of the operator's finger upon the lug g' of the shutter, the rear portion of the shutter moves upwards until it strikes the pin p, which lies within its path. The impact against this pin serves to always disengage the armature from the magnet if it has become stuck or frozen. The terminals of the coil are led out through rubber bushings in the rear of the tubular shell.

51. While this drop possesses the requisite degree of self-induction, and is also entirely free from cross-talk or other inductive troubles, it has a few rather objectionable features, chief among which is the fact that the shutter, when raised, exerts its maximum downward pressure upon the catch on the armature. In other words, instead of being balanced so as to exert little or no pressure upon the catch, it is supported by the catch in that position in which it is capable of exerting its full weight upon the catch. This increases the amount of friction between the catch and the shutter, and renders it more difficult for the armature to withdraw the catch than would otherwise be the case. In order to render this drop sufficiently sensitive for use on long lines, it becomes necessary to give it a very delicate adjustment, and when this is done, a slight jar of the switchboard will frequently cause several of the drops to fall.

52. American Electric Telephone Company's Tubular Drop.—Fig. 13 shows the tubular drop of the American Electric Telephone Company, in which the coil is enclosed in a tubular shield D, as before. This tube, however, is not made of one piece, its rear plate d being a separate piece screwed into position. The armature F carries a forwardly projecting arm f, and is pivoted at the points e in a bracket E secured to the lower portion of the tubular shield. The forward end of this bracket is secured to the rear face of an iron strip forming the front of the board. The shutter is maintained in its raised position by means of a catch on the end of the arm *f*, in an obvious manner. In this drop, the shutter is held by the catch in a position for maximum efficiency, as in the Warner drop; but there is a

FIG. 13.

slight disadvantage, due to the fact that in the attraction of the armature towards the magnet, the catch is pulled slightly to the rear before it lets go of the shutter, and is thus obliged to pull against the shutter before it can be released.

53. Double Magnet Drops.—For use on long cross-country lines, the drop shown in Fig. 14 is very efficient.

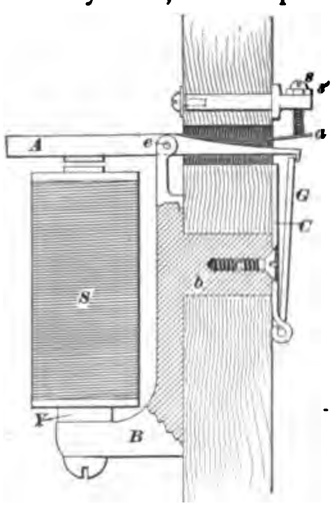


FIG. 14.

This has an electromagnet with two spools *S* (only one shown) mounted on a yoke piece *Y*, and presenting both poles to the soft-iron armature carried on the lever *A*. The magnet is mounted on a brass bracket *B*, secured to the rear of the switchboard panel, this bracket having a lug *b* projecting entirely through the panel. The plate *C* is secured by means of a screw *c* to this lug, and in the lower portion of this plate the shutter *G* is pivoted. The armature is of soft wrought iron and its lever *A* is pivoted in the bracket at the point *e*. The forward end of this armature lever carries a catch, which engages the upper edge of the shutter. A spring *a* is riveted to the upper portion of the armature lever and serves to maintain the catch on the forward end of the lever in its depressed position, so as to hold up the shutter. Against this spring bears an adjusting screw *s*, carried in a bracket mounted on the front of the board, by means of which the tension of the spring *a* may be varied at will. A small lock-nut *s'* serves to bind this screw in any desired position. Some manufacturers insert a small block of steel into the upper face of the shutter, in order that a sharp edge against which the catch bears may be maintained.

These drops may be adjusted to a maximum degree of sensitiveness, and are commonly used on long party lines having bridged telephones. When so used, the coils are wound to a joint resistance of 1,000 or 1,200 ohms, No. 36 B. & S., single silk-covered copper wire being used for the winding.

54. This drop will be seen to have the advantage of being entirely self-contained, all parts being mounted on the brass bracket *B*, and therefore not susceptible to any changes in the size or shape of the panel board upon which it is mounted. Drops of this kind are used where it is not necessary to economize space on the switchboard. This is usually the case in switchboards for toll lines, because the number of such lines entering the exchange is by no means so great as the number of local lines. Moreover, as toll lines are in most cases far more busy than local lines, a single operator can not attend to so many of them, and therefore the matter of space is not so important. Such drops may be mounted at a distance apart of not less than 4 inches between centers, without producing trouble from cross-talk. There is a tendency on the part of the two coils forming each electromagnet to neutralize the external field of the other. This is true because the currents flow through the two in opposite directions, and as they are placed side by side, their effects are differential rather than accumulative. Moreover, the path through both cores, yoke, and armature forms a complete iron circuit except for the small air-gap between the cores and the armature, so there is very little tendency for any lines of force to stray into the surrounding region.

55. Drops for Bridge Lines.—For bridged party lines in general, it is often necessary for the drop to make a considerable noise when actuated, in order that the operator may determine by its sound whether the call is for her or for some other party on the same line. This is true in all cases where a code of signals is used to designate the particular station being called. Sometimes a magneto-bell is placed in multiple with the drop at the switchboard, in order that the operator may receive the signal by ear as well as by sight; but as such a bell always reduces the efficiency of the drop to some extent, it is not advisable to do this, especially in the case of a long, heavily-loaded line. By giving the armature of the drop a rather wide play, it usually makes a sufficient noise for the operator to distinguish between calls for some other party on the line and those for the switchboard.

JACKS AND PLUGS.

56. Economy of Space.—In the design of spring-jacks, especially for use in large switchboards, the economy of space is an important consideration. This will be made more apparent when the subject of multiple boards is considered, for in those boards each operator must have within her reach a jack for every line in the exchange. For small boards, however, the question of space is not so important, as the number of jacks within the reach of the operator need not be so great.

57. Simple Metallic Jack.—In Fig. 15 is shown a form of metallic-circuit jack similar to that in Fig. 8. The tip spring *t*, however, is held in place by the same screw *s* which forms the terminal of the line-wire which connects with the frame of the jack. This screw passes through an insulated bushing, through the spring *t*, and into the metallic portion of the jack. The jack is held in place against the rear face of the board *B* by means of a threaded bushing *C*, which passes through the board from the front, and engages a corresponding screw-thread on the main portion of the jack. A slot is provided in the front of the bushing *C*, in order that the jack may be readily removed from the panel with a screw-driver.

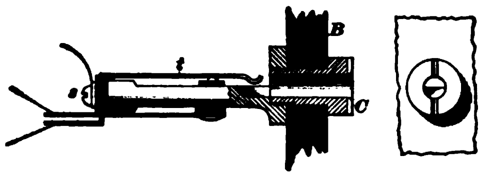


FIG. 15.

58. Double-Spring Contact.—It has been found unsatisfactory to rely upon the contact between the sleeve of a plug and a tubular bushing, such as is shown in Figs. 8 and 15. In both of these figures, the connection with the tip of the plug, which is made in each case by means of the spring *t*, is reliable; but the contact between the sleeve of the plug and the inner surface of the bushing is likely to

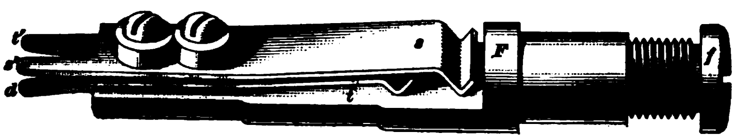


FIG. 16.

become loose and the surfaces dirty, so that a poor connection results. In Fig. 16 is shown a spring-jack where both the tip and sleeve connections are made by means of springs.

In this, the framework *F* is secured in position on the panel board by means of a screw-threaded sleeve *f*, as in Fig. 15. The tip and sleeve springs *t* and *s*, respectively, are mounted upon the rear portion of the frame by means of two screws passing through the springs and the layers of insulation between them and into the metallic frame.

These screws are of course insulated from the springs by means of hard-rubber bushings through which they pass. The rear portions of the springs have projecting tongues *s'* and *t'*, to which the line connections may be soldered; a similar tongue *d* also projects from the frame *F*, thus forming a terminal for it. The tip spring *t* normally rests upon a projection on the frame *F*, in order to complete the connection through the drop, but the insertion of the plug lifts *t* and causes this connection to be broken. One line-wire is connected to *t'*, the other to *s'*, and the annunciator between the terminal *d* of the frame *F* and *s'*.

59. Metallic-Circuit Plug.—A metallic-circuit plug is shown in section in Fig. 17. The tip conductor *t* is

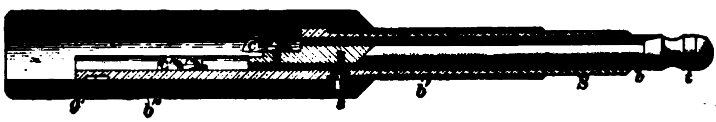


FIG. 17.

formed of a brass rod having an enlargement at its forward end. All except the enlarged portion of this rod is encased in a hard-rubber bushing *b*, and over this is slipped a tube *S* of brass, forming the sleeve conductor. The rear portion of this latter sleeve is covered by a second hard-rubber bushing *b'*, and over this is slipped a heavy bushing *b''*, which forms the handle of the plug. Carried on the rear portion of the tip conductor *t* is a connector *c*, adapted to form the terminal of one of the cord conductors. A similar connector *c'* is carried on the rearward extension of the sleeve conductor *S*, and this forms the terminal of the other conductor of the cord. These tips *c* and *c'* are shown attached to the cord conductors in Fig. 18. The bushing *b''*, forming the handle, is not put in place until after the cord is attached to the terminals *c* and *c'*, after which it is slid over the plug and the cord and is secured by the screw *s*, engaging a tapped hole in the tip conductor *t*. This screw passes through, but is insulated from, the sleeve *S*. The groove *g* on the rear portion of the sleeve conductor is for the purpose of binding the flexible cord in place by means of a strong linen thread lying within the groove and wrapped tightly around the cord. By this means the strain, due to the weight of the cord and pulley, is not exerted at the junction of the conductors and the connectors c and c', but is carried rather by the covering of the cord, owing to its being rigidly bound to the rear portion of the sleeve.

60. Cord Connectors in Plug.—The manner of making this connection between the cord and plug is more clearly shown in Figs. 18 and 19, in which C is the cord, having two insulated conductors t' and s'. These conductors are bared at their terminals and

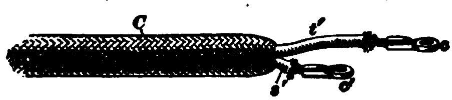


FIG. 18.

clamped between the small lugs projecting from the connectors c, c', after which they are securely soldered. The connectors c and c' are then screwed in place, after which the cord is securely bound to the sleeve tube by means of

FIG. 19.

the linen thread l, which is wrapped in the groove, as shown. Before slipping on the sleeve b'', Fig. 17, it is well to give the connectors a coating of shellac, as this tends to prevent any loose ends of the tinsel strands of which the conductors are formed from making short circuits within the plug.

It is not difficult to see that unless a plug is constructed with the greatest care, it will be a source of endless trouble, for the various parts are necessarily placed so very close together that any loose ends or poorly constructed joints are almost sure to form short circuits or open circuits. Especially is this true in the case of some plugs in use with more complicated systems, in which three separate conductors are used within the flexible cord, thus necessitating three separate contacts on the plug, all of which must, of course, be insulated from each other.

FLEXIBLE CORDS.

61. Old Form of Flexible Cord.—The flexible conductors, by which the temporary connections between the terminals or spring-jacks of subscribers' lines are made, are usually termed cords, and as in all other branches of telephony, their construction, in order to give satisfactory service, demands the most careful attention to the minutest detail. A form of cord, the structural details of which are shown in Fig. 20, has been in rather wide use among the

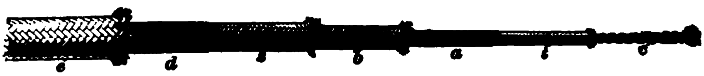


FIG. 20.

independent companies, but has been generally discarded because it has proved incapable of giving satisfactory service. In this, the tip conductor *t* was formed of fine strands of tinsel, braided together around a stout hemp cord *c*. Over the conductor *t* was tightly wrapped a layer *a* of floss silk, and over that braided a coarser layer *b* of cotton. The sleeve conductor *s*, composed, like the tip conductor, of strands of tinsel, was then braided over this layer of cotton and covered with another wrapping *d* of silk, and an outside braiding *e* of polished cotton. In this, the strong cord through the center was for the purpose of giving strength, while the braids of silk and cotton were for the purpose of insulating and protecting the concentric conductors. It was found impossible, after a long trial of these cords, to so insulate the conductors that short circuits would not be formed, due to the broken ends of the tinsel strands of one conductor working their way through the intermediate braiding and making connection with the other conductor. It was also found practically impossible to prevent the breaking off of the tip or sleeve conductors at a point just back of the handle of the plug. This is the point in a cord that is subject to the greatest amount of wear, because it is most frequently handled by the operator, and a sharp bend always occurs, due to the side strain on the cord, when a plug is inserted in a jack.

62. Modern Flexible Cord.—The type of cord shown in Fig. 21 has been found to be very satisfactory, and is available to the independent and also to the Bell companies.

FIG. 21.

In this, the tip and sleeve conductors *t* and *s* are each composed of twisted strands of tinsel, with which a few strands of fine copper wire are intermingled for the purpose of giving greater strength. It has been found that a twisted tinsel conductor is better than a braided one, on account of being more flexible. Around each conductor is wrapped a layer of floss silk *a*. It has been found preferable to make the first layer of insulating material a wrapping instead of a braid, because the former tends to bind the strands of the conducting cord more closely together, thus reducing the liability of the ends breaking off and projecting through the insulating layers to form short circuits. Over the layer of silk is a braiding *c* of cotton rather loosely laid on. After being thus insulated, the two conductors are laid together and served with a wrapping of thread *d*, which binds them into a single cord. A spiral shield of spring brass wire *e* is then slipped over the two conductors, after which a layer of polished cotton is braided tightly over the whole. The spring brass shield serves as a mechanical protection for the cords without impairing their flexibility. Its most important function is to prevent sharp kinks in the cord, which have been found to be very destructive to the conductors within. In order that the end of the cord which receives the most handling and which is the most liable to be sharply kinked may receive an additional stiffening, the outside layer of cotton is made double for a distance of about one foot back of the heel of the plug.

63. It is important in cords of this kind that the spiral brass wire shield should be thoroughly anchored at each end, and this is accomplished by wrapping it at each end with strong thread, so that it can not slide along the conductors. As an addition to this anchoring, the outer braiding of the cord should be made very tight at each end.

CORD FASTENINGS.

64. Split Bushing.—A good method of fastening the stationary ends of switchboard cords is shown in Fig. 22.

FIG. 22.

The cord is clamped by means of a split bushing, shown in detail at the left of this figure. This bushing is composed of two pieces of wood or fiber, which, when laid together, form a conical plug adapted to fit loosely in a hole bored in the rack on which the cords terminate. The cord to be secured is placed between the two halves of the bushing, which is then pushed into the hole in the rack, and thus serves to clamp the cord tightly without in any way deranging its internal structure. This clamp has proven very convenient in practice, as by it a cord may be clamped in any position desired or entirely removed, almost instantly. The clamp does not injure the cord, which is not the case with many other forms of attachments. Another way to attach a cord to the switchboard is to leave a portion of its external braiding projecting beyond the end of the cord, and to tie the cord in position by this means. This has the disadvantage that it clamps only the end of the cord, and if for any reason it becomes necessary to secure the cord at an intermediate position, some other means must be resorted to.

65. Connections on Terminal Rack.—The connectors to which the stationary terminals of the cords are secured

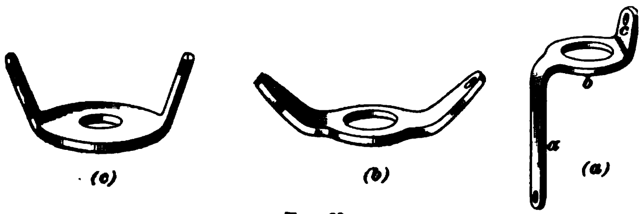


FIG. 23.

should be fastened rigidly to the cord rack and should present suitable means for attaching the cord conductors without injuring them, and also for attaching the wires with which the cord conductors are to be connected. It is not an altogether easy matter to solder tinsel without burning it, and therefore some manufacturers prefer to clamp the cord terminal between the connector and a washer by means of a screw passing through the two, this method being shown in Fig. 22. Frequently the wire with which the cord conductor is to connect terminates on the opposite side of the connecting rack from the cord, and in this case such a connector as is shown at (*a*), Fig. 23, is much used. In this connector, the strip *a* formed integral with the washer portion *b*, is bent at right angles to the body of the connector and projects through a small hole in the board of the terminal rack so as to form a suitable terminal to which the wire on that side of the board may be soldered. The upwardly projecting tongue *c* may or may not be present, according to whether other connections are to be made at this point. The connectors shown at (*b*) and (*c*), Fig. 23, are for use where the wire or wires terminate on the same side of the rack as the cord conductor. When it is desired to solder the cord conductor into place, wire terminals are preferably placed on the ends of the conductors. Such a terminal may be readily made by inserting a piece of No. 22 B. & S., tinned copper wire, about 6 inches long, clear through the cord conductor just back of the end of the braid, as is shown in the left-hand portion of Fig. 24. The two

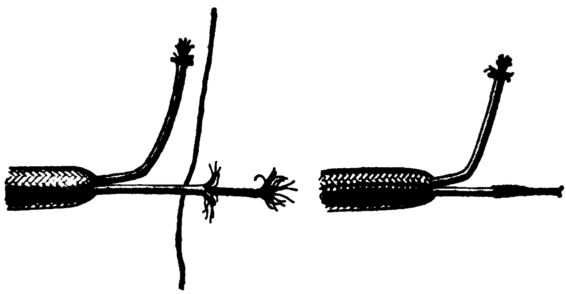


FIG. 24.

ends of this wire are then twisted closely around the end of the cord, making a firm metallic connection with the tinsel by binding them closely within the convolutions of the wire. The completed terminal may be made in a minute, with no other tools than the fingers and a pair of pliers, and is shown when finished in the right-hand portion of Fig. 24.

66. Connectors.—The connectors shown in Fig. 23 are preferably stamped from sheet German silver or from soft sheet copper. They should be polished, usually by tumbling, and be entirely free from oil, which would interfere with the use of solder. Where copper is used, the tips of the connectors should be tinned by dipping them in acid and then in molten tin. In order to prevent the acid from corroding the surface of the metal after a time, they should be dipped, after being tinned, in alcohol, which has been found to almost entirely prevent future corrosion.

SELF-RESTORING SWITCHBOARD DROPS.

67. In the switchboard drops so far described, the construction was such that it was necessary for the operator to manually restore the shutters, in order to make them ready for another call. This, in an exchange where the operator is necessarily kept very busy, is a disadvantage, inasmuch as it increases the number of motions she is required to make in establishing connections between subscribers. One object to be kept in view in the design of switchboards for modern exchanges is to reduce the number of motions necessary on the part of the operator to a minimum, and one of the most important steps in this direction was the introduction of the so-called self-restoring drop. The shutter of this drop is restored to its normal position automatically, the movement being accomplished as a secondary result of some of the other necessary operations, such, for instance, as the insertion of a plug into a jack.

68. The manner of imparting the restoring motion to a shutter has been brought about in two general ways: one by the action of an electromagnet, the circuit of which is closed by some necessary motion of the operator, such as the insertion of a plug into a jack, and the other by mechanical means, the plug itself serving to mechanically push the shutter into its restored position, either by direct contact or through the intervention of some connecting mechanical link.

69. Electrically Restoring Drops.—In Fig. 25 is shown the details of one of the most commonly used electrically restoring drops. This is really composed of two tubular magnets *a* and *d*; each of these are secured to a plate *b* corresponding to a similar plate used in connection with the Warner tubular drop, already described. The rear electromagnet *a* is in reality a slightly modified Warner drop, having its armature *C* pivoted at *c* in a bracket carried on the rear portion of the tubular shell. The second tubular magnet *d* has its poles projecting towards the front of the board, and is provided with a heavy armature *e* pivoted at its lower edge by the pivot screws e' and e'', which are held in a lower bracket *h* secured to the front end of the tubular magnet *d*. The rod c''' secured to the armature *C* is made longer than in the Warner drop, so as to reach forwards and engage the lug e''' on the upper side of the front armature e. Pivoted on the bracket f, attached to the upper side of the magnet d, is a light aluminum shutter g hanging directly in front of the armature e. When released by the action of the armature C of the electromagnet a, the front

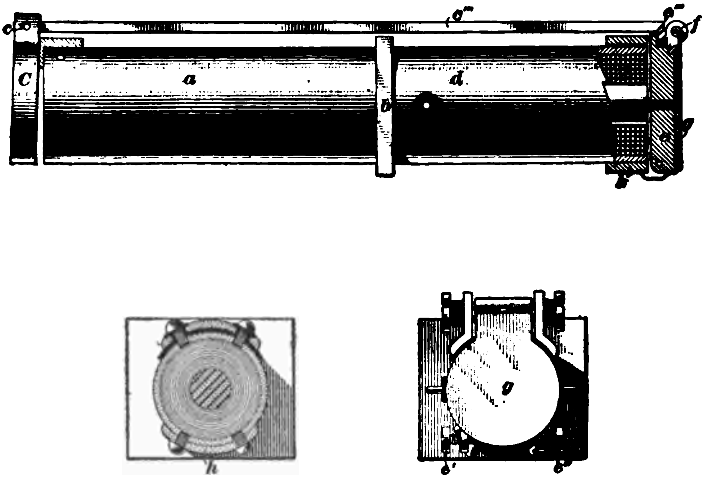


FIG. 25.

armature e falls forwards by its own weight and pushes the light shutter g out of its path in so doing. This raises the shutter g, so as to display any number or signal behind it and on the face of the armature e to the view of the operator. The connections are so made with the winding of the magnet d that when an operator inserts a plug into the jack of the corresponding line, the circuit through the magnet d will be made complete, and as the circuit includes a battery, the magnet will be energized and the armature e reattracted, thus allowing the shutter g to resume its normal position.

70. Operation of Electrically Restoring Drop.—In order to render the operation of this drop more clear, the circuits leading to both the line magnet a and the restoring magnet d are shown in Fig. 26. In this figure, l represents the line-wires leading to a subscriber's station. Connected across these two wires at the central office is the line magnet *a* of the drop. The springs *t* and *s* are connected, respectively, with the two sides of the line-wire, and form, in connection with the metallic-contact sleeves or thimbles *k* and *k'*, the spring-jack belonging to that line. The tip and sleeve contacts of the plug are represented by *t'* and *s'*, and a third contact *s"*, merely a brass collar or sleeve, is provided on the plug for making an electrical connection between the two thimbles *k* and *k'* of the jack, when the plug

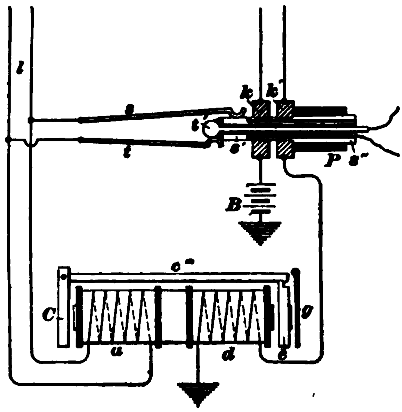


FIG 26

is inserted. The thimble *k* is grounded through a battery *B*, and one terminal of the electromagnet *d* of the drop is connected with the thimble *k'*, while its other terminal is grounded. When a current from the subscriber's station comes over the two wires of the metallic circuit *l*, the electromagnet *a* is energized, and by attracting its armature *C* releases the forward armature *e* and allows it to push the shutter *g* out of its normal position. When an operator inserts the plug *P* for the purpose of answering this call, the tip and sleeve contacts *t'* and *s'* on the plug make contact, respectively, with the tip and sleeve springs *t* and *s* of the jack, and thus connect the cord circuit across two sides of the line circuit. At the same time, the second sleeve *s"* on the plug short-circuits the two thimbles *k* and *k'*, thus completing the circuit through the electromagnet *d* and battery *B*, this circuit being traced from the positive pole of the battery through thimble *k*, sleeve *s"*, thimble *k'*, winding of magnet *d*, to ground, and by ground to the negative pole of the battery. The energizing of this magnet causes the attraction of the forward armature *e*, and allows the shutter *g* to fall into its normal position. It is thus seen that the restoring of the shutter is performed without any additional effort on the part of the operator.

MECHANICALLY RESTORING DROPS.

71. Western Telephone Construction Company's Drop.—The first mechanical restoring drop to come into wide use was that shown in Fig. 27. In this, as

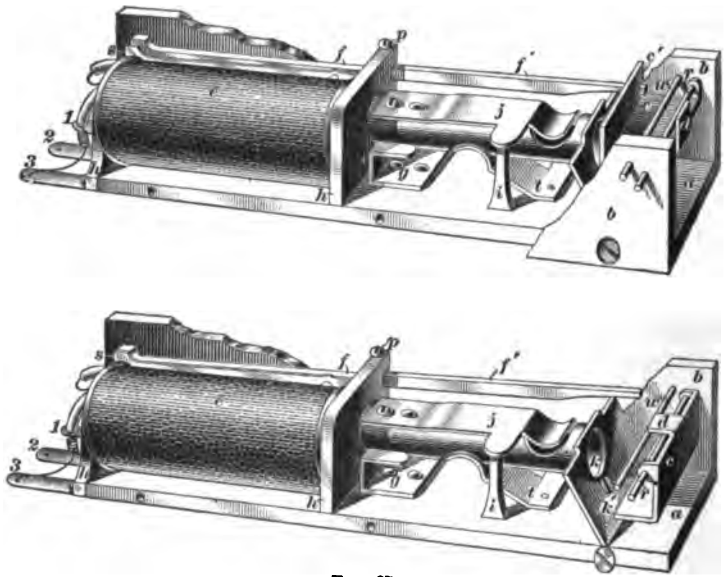


FIG. 27.

in nearly all other drops of this type, the jack and drop are so closely associated as to form practically one piece of apparatus. The base-plate *a* in this particular combination of drop and jack is of hard rubber, 1 inch in width, 4 inches in length, and $\frac{3}{16}$ of an inch in thickness. On this is mounted the electromagnet *e*, and directly in front of it the spring-jack. When in place in the switchboard, the base-plates are secured between vertical sheets *b* of hard rubber, extending the entire height of the board. A section of 100 complete jacks and drops occupies a space about

14 inches square, there being 10 vertical rows between the vertical plates *b*, each row containing 10 drops. The framework is therefore entirely of hard rubber, and resembles in appearance a packing-case for eggs, having 100 compartments. The coil *e* of the electromagnet is wound upon a spool formed of a soft-iron core riveted into the ends of the two soft-iron heads *h*, *h*. In the front head is pivoted an armature *f*, by means of the pivot screws *p*, *p*, of which but one is shown. The rear end of the armature *f* extends to a point opposite the rear head *h*, and is normally held at a slight distance therefrom by means of the leaf spring *s*, which is riveted to the inner face of the armature near its pivot screw *p*. This spring is of very thin German silver, and serves to not only hold the armature away from the rear head, but also to prevent its sticking when attracted by a strong current.

72. The shutter *c* is of German silver hung on a German-silver wire *r*, which is common to all shutters in a horizontal strip. This shutter is provided with a catch or notch *c'* on its right-hand side piece, which is adapted to hook over a forwardly projecting rod *f'* forming a portion of the armature, thus normally maintaining it in its horizontal position, as shown in the upper portion of Fig. 27. When, however, the armature is attracted, the rod *f'* slides out of the notch *c'* and allows the shutter to swing into a vertical position, as shown in the lower view, in which position it is distinctly visible to the operator. The jack is composed of a tubular portion, having riveted to its upper surface the sleeve spring *j*, which has a lug projecting to the left and normally resting upon the cut-out pin *i*, which is connected with the strip *3* projecting from the back of the base. A brass guide plate *k* is secured to the front of this tube, and is held by a screw *k'* to a small brass lug, not shown, which is riveted to the base-plate. This plate *k* thus forms a support for the front of the tube and also a guide for a plug in entering the jack, it being formed with a concave face so as to facilitate the entrance of the plug. The rear portion of the jack tube engages the heel piece *g*, riveted to the base-plate, the arrangement being such that by removing the small screw *k'* the entire jack tube may be withdrawn from the front of the board. The tip spring *t* is also riveted to the base-plate, and bent upwardly so as to lie within a notch in the lower side of the jack tube without touching the tube.

73. When a plug is inserted into the jack, its tip makes contact with the spring *t*, while its sleeve makes contact with the spring *j*, and lifts it from engagement with the pin *i*, thus cutting out the coil *e*, one terminal of which is connected through strip *3* to *i*. When the shutter *c* falls, it assumes a position directly in front of the jack tube, and therefore a plug can not be inserted without lifting the shutter into its normal position. In practice, the operator, seeing the shutter fall, plugs directly against it, as if it were not there, the point of the plug pushing up the shutter and entering the jack. The tip spring *t* is connected directly with the strip *1*; the heel piece *g*, and therefore the sleeve spring *j* and the tube, are joined directly with the strip *2*, and, as before stated, the pin *i* with the strip *3*. Terminals *1* and *2* are connected to the line-wires, while the coil *e* is connected between terminals *2* and *3*.

The wire *r*, upon which all the shutters are hung, forms one terminal of the night-alarm circuit. Another wire *w*, supported in a similar manner to the former wire, forms the other terminal of this circuit; and when any shutter falls, the lug *d*, projecting from its upper portion, strikes the wire *w*, and thus completes the circuit between them. This rings the night-bell in the manner described in Art. **15.**

74. This combined drop and jack, as recently constructed, has given very good satisfaction, although it is subject to several radical faults. The tip and sleeve springs, especially the former, are entirely too short to give the best results; and the fact that the shutter rests about half its weight while in its horizontal position upon the forward end of the long arm *f'* makes it impossible to attain a high degree of sensitiveness, on account of the friction to be overcome when f' releases it. The shutter is always supported in that position in which it is capable of exerting a maximum pressure on the armature.

75. In Fig. 28 is shown an improved form of the drop just described, recently designed by the same company.

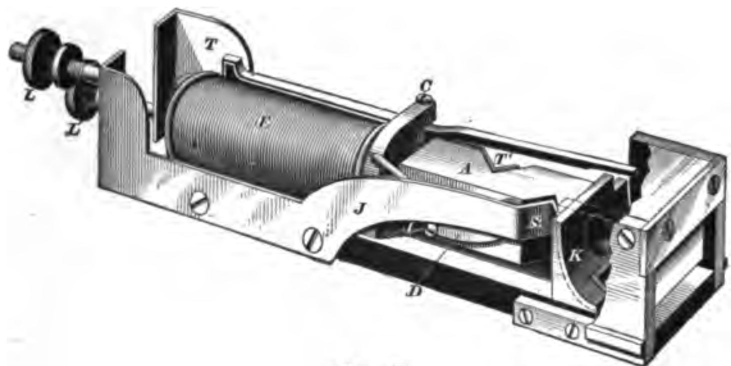


FIG. 28.

The entire mechanism, as shown in this figure, is adapted to be put in position in the board from the front, the two screws L and L' passing through a panel at the back of the switchboard cabinet and secured in place by the thumbnuts. These screws L and L' form the terminals of the line circuit, one of them being connected to the plate J, of which the sleeve spring S forms a part, while the other is connected with the plate T, of which the tip spring T' is a part. The jack tube A is cast in one piece with the guide-plate K. The coil E is connected between the tip spring T' and the spring D, mounted on the side of jack tube A, and as the sleeve spring J normally rests against the spring D, the circuit between the two terminals L and L' is normally completed through the coil E. The operation of this improved mechanism will be readily understood from the description of Fig. 27.

76. American Electric Telephone Company's Drop and Jack. — This combined drop and jack is shown in Figs. 29 and 30, and the plug, which is of special construction, in Fig. 31. In Fig. 29, the entire mechanism of one drop and jack is shown in perspective, while Fig. 30 is a plan view of the mechanism with the drop magnet removed.

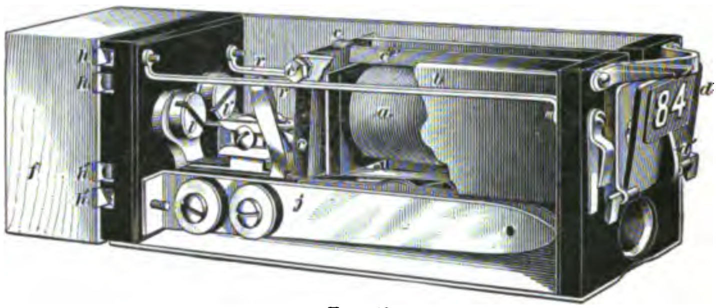


FIG. 29.

The drop magnet is mounted directly above the jack, and the shutter is so arranged that when released by the armature, a projection on it falls in front of the jack opening.

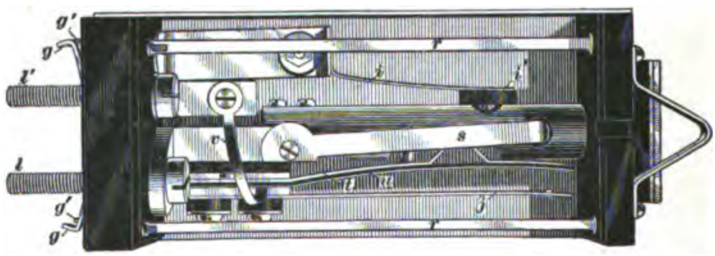


FIG. 30.

The plug carries a collar, which, during the insertion or withdrawal of the plug from the jack, engages this projection on the shutter and serves to mechanically raise the shutter to

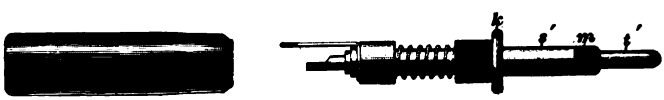


FIG. 31.

its normal position. The back panel of the switchboard is shown at *f*, Fig. 29, and is provided with two openings for each jack, through which the machine-screws *l* and *l'* pass when the combined drop and jack is in place. These two screws *l* and *l'* serve not only to hold the drops and jacks in place, but also as a means for connecting the line terminals with the various circuits of the mechanism. The back panel *f* is also provided with strips *h*, *h* and *h'*, *h'* with which the springs *g*, *g* and *g'*, *g'*, secured to the back of the drop, engage when the drop is clamped in position. The two lower strips *h'*, *h'* form the terminals of the switchboard generator, and the springs *g'*, *g'* are connected, respectively, with the long spring *j* and the spring *i* on the opposite side of the jack, so that these two springs *j* and *i* form terminals of the switchboard-generator circuit. The line springs *t* and *s* are arranged between the generator springs and are adapted to make contact with the tip and sleeve conductors *t'* and *s'*, respectively, of the plug, when inserted into the jack. The line spring *s* is connected directly with the terminal screw *l*, while the line spring *t* is connected through the coil *a* of the drop with the other terminal screw *l'*.

77. The drop is composed of the electromagnet *a*, included in a sheet-iron box *b*, forming a partial magnetic shield for the prevention of cross-talk. The armature *c* is pivoted, as shown at *c'*, at the rear portion of this shield, and has a forwardly projecting lever *c"*, holding the shutter *d* in position in the ordinary manner. The projection on the face of the shutter, which falls in front of the jack opening when the shutter is down, is shown at *d'*. When the plug is inserted into the jack, the collar *k* on the plug engages the cam surface on the projection *d'* and forces the shutter into its raised position. If while the plug is in, the drop is again actuated as a clearing-out signal, the projection *d'* falls in front of the collar *k*. By this means, when the plug is withdrawn from the jack, the collar *k* will again be pressed against the projection *d'*, again restoring the shutter.

78. It has been said that the terminals of the switchboard-generator circuit were brought into proximity with each jack by means of the springs *j* and *i*; one, *j*, occupying a position opposite the tip spring *t* of the jack, and the other, *i*, a similar position on the other side of the jack tube. In order to call a subscriber, therefore, the operator has only to press the plug into the jack as far as it will go. This causes the collar *k* to slide back on the plug against the pressure of the spring within the plug handle. The tip spring parts contact with the tip of the plug *t'*, and rides upon the enlarged portion *m*, thus forcing spring *u*, lying parallel to the tip spring, into engagement with its generator spring *j*. This connects one terminal of the generator to the line screw *l'* through the spring *j*, spring *u*, and metallic strip *v*. The sleeve spring is at the same time electrically connected with the generator spring *i*, because the sleeve *s'* on the plug touches both the sleeve spring *s* and the tip spring *i*. Thus the two sides of the line are connected with the terminals of the switchboard generator.

The two strips *r*, *r* projecting from the front of each jack form the terminals of the night-alarm circuit, the connection to them being completed by means of the springs *g*, *g* and the strips *h*, *h*, already referred to. When the shutter falls, it bridges across the two wires *r*, *r*, thus completing the circuit and sounding the bell.

LISTENING AND RINGING DEVICES.

79. The O'Connell Key.—In establishing a connection between two subscribers, several different switching operations have to be performed by the operator in connecting her telephone with the circuit of the calling subscriber, and later across the circuit of both subscribers, and also in ringing either one or the other of the subscribers, as conditions may require. To accomplish these changes, many forms of switching mechanisms have been devised. One of these, invented by Mr. J. J. O'Connell, is shown in Fig. 32, the four different positions which the parts may assume being represented at (*a*), (*b*), (*c*), and (*d*). This switch, or key, as devices of this kind are usually called, is composed of six springs *a*, *a*, *b*, *b*, and *c*, *c*, adapted to make various contacts between themselves and between the pairs of contact pins *d*, *d*, *e*, *e*, and *f*, *f*, as will be described. These

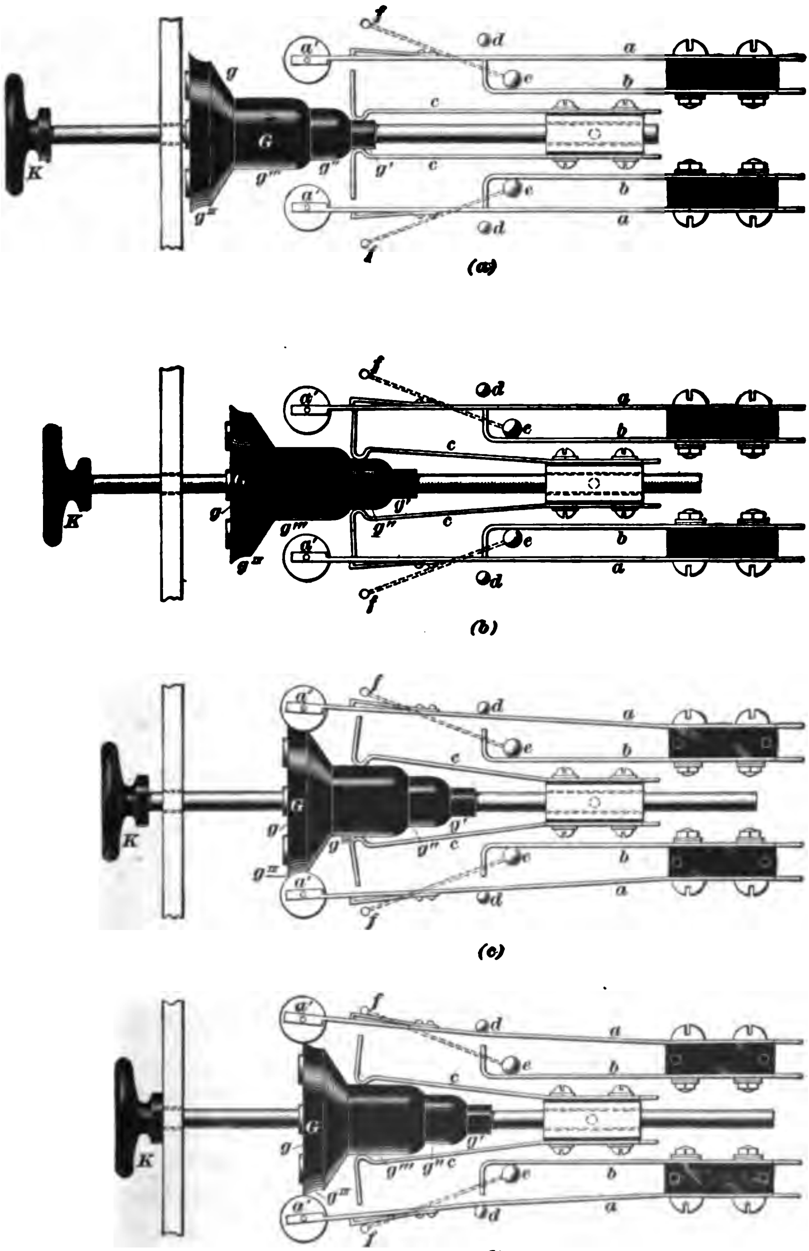


FIG. 32.

springs are acted upon by a cylindrical wedge *G*, so mounted as to slide vertically among the springs, and so formed as to bring about the various desired changes of circuit, when occupying any one of its four positions among them. The circuits by which this key is connected with the pairs of plugs, the switchboard generator, and the talking set are shown in Fig. 33. The springs *a*, *a* form, respectively, the

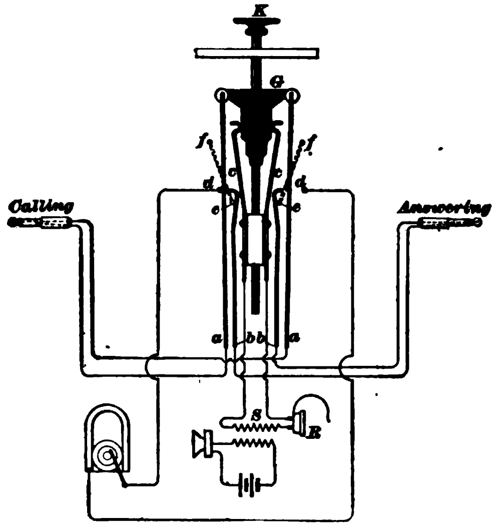


FIG. 33.

terminals of the tip and sleeve strands of the calling plug. In a like manner, the springs *b*, *b* form the terminals of the tip and sleeve strands of the answering plug. The springs *c*, *c* form the terminals of the operator's secondary circuit, including between them the secondary winding *S* of the induction-coil and the head receiver *R*. The pins *d*, *d* form the terminals of the switchboard generator, and the pins *e*, *e* are connected, respectively, to the pins *f*, *f*, but to nothing else.

80. Operation.—The normal position of this key is when the operating button *K* is raised to its fullest extent. In this position it is shown at (*a*) in Fig. 32, the operator's springs *c*, *c* resting on the smallest portion *g'* of the wedge *G*. These springs touch no others in this position, and therefore form no connection with the other parts of the apparatus, but the springs *a*, *a*, on each side, rest on the corresponding springs *b*, *b*, thus connecting the tip of the calling plug to the tip of the answering plug and the sleeve of the calling plug to the sleeve of the answering plug. In this position, the circuit between the two plugs is not broken, and if these plugs are connected with the lines of two subscribers, the subscribers may converse without being heard by the operator. The next downward movement of the button brings the key into the listening position, as shown in (*b*), in which the springs *a*, *a* and *b*, *b*, on each side of the key, remain in contact as before, but the springs *c*, *c*, which have ridden upon the second step g'' of the wedge, have come into contact with the springs *a*, *a*, thus connecting the operator's telephone circuit across the tip and sleeve strands of the two connected cords. In this position the two subscribers may still converse, and the operator is enabled to listen in for the purpose of conversing with either or of ascertaining whether or not the line is in use. The further depression of the button *K* brings the key to the ringing position shown in (*c*), in which the springs *c*, *c* have ridden upon the portion g''', and the rollers a', a', carried upon the springs *a*, *a*, have ridden into the hollow in the largest portion of the wedge *G*. The motion imparted to the springs *a*, *a* by the enlarged portion of the wedge lifts them from engagement with the springs *b*, *b*, and also with the springs *c*, *c*, but presses them into engagement with the pins *d*, *d*, thus connecting the circuit of the generator across the tip and sleeve strands of the calling plug. In the fourth position, which is not often used, the button *K* is depressed to its fullest extent, as is shown in (*d*). This still retains the springs *a*, *a* in contact with the generator pins *d*, *d*, but also presses the ends of these springs outwardly against the pins *f*, *f*. The springs *b*, *b* are already in contact with the pins *e*, *e*, which, as has been shown, are permanently connected with the pins *f*, *f*, and the result is that the tip and sleeve strands of both the calling and answering plugs are connected together through the pins *e*, *e* and *f*, *f*, and the generator circuit is connected across the circuit of the two plugs through the pins *d*, *d*. This position is only used when the calling subscriber has for some purpose left his instrument, and the operator desires him to return.

It will be seen that this key affords no means for connecting the switchboard generator with the calling subscriber without at the same time connecting it with the called subscriber. In later forms of keys, means are provided whereby the operator may call either subscriber at will without calling the other.

81. The Cook Key.—A form of key of more modern design is shown in Figs. 34 and 35. This key is the invention of Mr. F. B. Cook, and is used quite extensively by certain licensees of the American Bell Telephone Company. It is now manufactured by the Sterling Electric Company, of Chicago. The entire mechanism of the key is included in a sheet-metal casing *A*, the various springs being mounted on the hard-rubber base-plate *B*. The chamber within this casing is divided by an insulating plate *C*, on the opposite sides of which are arranged in a symmetrical form the various contact springs by which the changes are brought about. The various movements are imparted to the springs by means of a cam *D* of hard rubber, pivoted between the two metallic plates *E* and *E'*, as shown most clearly in Fig. 34, and also by the two

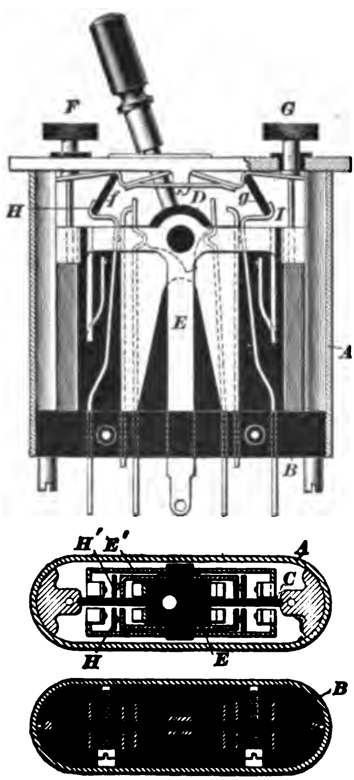


FIG. 34.

buttons *F* and *G* acting through the hard-rubber rods *f* and *g* upon the pairs of springs *H*, *H'* and *I*, *I'*, respectively.

82. The operation of the device will be more readily understood after a consideration of the various circuits,

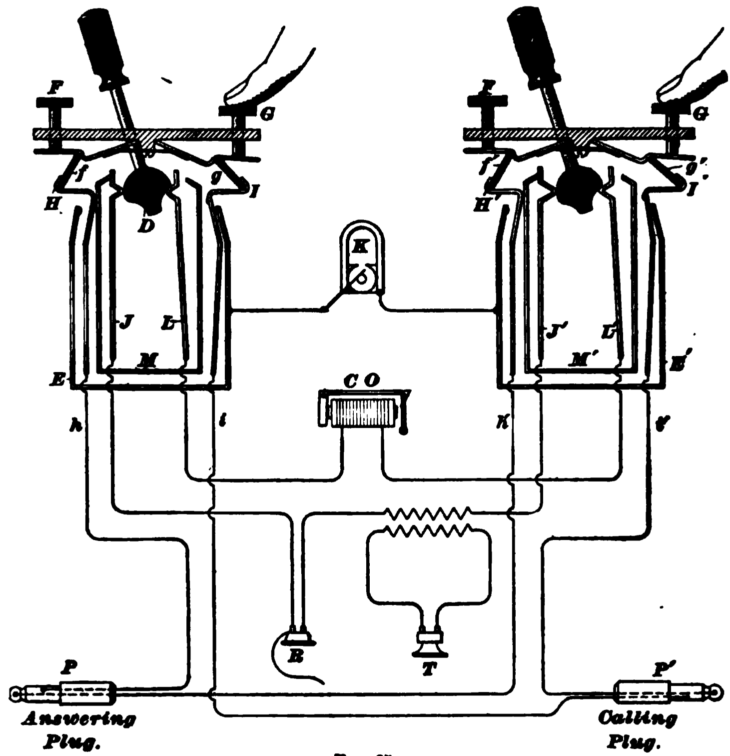


FIG. 35.

which are shown in Fig. 35. For the sake of clearly illustrating the circuits, the sets of springs on the two sides of the insulating partition *C* are removed from each other, but it should be remembered that whatever motion is imparted to the springs on one side of *C* by the action of the lever *d* or of the push-buttons *F* and *G* is also imparted to the springs on the other side. This condition is brought about by making the cam *D* and also the rods *f* and *g* wide enough to engage both of the springs in a pair. For further clearness, the springs and contacts on one side of the dividing partition are designated by capital letters, while the corresponding springs on the other side are designated by the same letters with prime marks.

83. The operator's receiver is shown at *R*, the operator's transmitter at *T*, the clearing-out drop at *C O*, and the answering and calling plugs, respectively, at *P* and *P'*. The springs *J* and *J'*, engaging the left-hand portion of the cam *D*, form terminals of the operator's secondary circuit, including her receiver *R* and the secondary of her induction-coil. The strips *E* and *E'*, which are shown, for the purpose of diagrammatic illustration, in a modified form, form the terminals of the switchboard generator *K*. The springs *H* and *H'* are connected, respectively, with the sleeve and tip strands *h* and *h'* of the answering plug *P*, and in like manner, the springs *I* and *I'* are connected, respectively, with the sleeve and tip strands *i* and *i'* of the calling plug *P'*. It will be noticed that the strips *E* and *E'*, forming the terminals of the generator, have contacts upon their left-hand ends in proximity to the sleeve and tip springs *H* and *H'*, and upon their right-hand ends with the sleeve and tip springs *I* and *I'*. The clearing-out drop *C O* is connected between the pair of springs *L* and *L'*.

84. Operation.—In the normal position of the apparatus, the lever *d* occupies a vertical position, and the calling buttons *F* and *G* their uppermost positions. In this position, the sleeve strand *h* of the answering plug is connected with the sleeve strand *i* of the calling plug, and the tip strand *h'* of the answering plug with the tip strand *i'* of the calling plug. The connection between the sleeve strands is made through the answering sleeve spring *H*, which rests against the contact strip *M*, the other end of which is in engagement with the calling sleeve spring *I*. In a similar manner, the connection between the tip strands is made by the answering tip spring *H'* resting against the contact strip *M'*, against the other end of which rests the calling tip spring *I'*. In this condition, two subscribers' lines, with which the plugs P and P' are in engagement, will be connected together for conversation.

In answering a call, the operator inserts the plug P in the jack of the calling subscriber, and presses the lever d into the position shown in Fig. 35. This connects the springs J and J', forming the terminals of the operator's set, with the springs H and H', forming the terminals of the tip and sleeve strands, respectively, of the answering cord, the connection being made in each case through the contact strips M and M', situated on each side of the dividing partition. This bridges the operator's telephone across the terminals of the answering cord, and enables her to communicate with the subscriber. Having learned the number of the subscriber wanted, the operator inserts the calling plug P' into the jack of subscriber wanted, and presses the button G, as shown in Fig. 35. This presses the springs I and I' on the calling plug into engagement with the generator springs E and E', and thus sends current to the line of the called subscriber. The depression of the button G also breaks contact between the springs I and I' and the strips M and M', and therefore breaks the circuit between the calling and the called subscriber. It also insures, by the breaking of the contacts between the springs L and L' and the strips M and M', that the clearing-out drop $C\ O$ will not be operated when one or the other subscribers are called, which is a feature possessed by few keys. To call the original calling subscriber, it is only necessary to depress the button F which connects the springs H and H' of the answering plug with the generator terminals E and E', at the same time breaking the circuit with the other plug, because G returns to its normal position when the finger is removed from it, and also with the clearing-out drop and operator's set, as before described. It is thus possible for an operator to talk with one subscriber while she is calling the other, for the circuits of the calling and answering plugs are entirely distinct during such operation, as shown by the position of the springs in Fig. 35. The terminals of the various springs and contacts project through the bottom of the base-plate *B*, in order to afford convenient connectors to which the wires leading to the mechanism may be soldered.

85. An excellent feature of this key is that it is entirely enclosed, so as to be free from the accumulation of dust. Another good feature is that the key for each pair of plugs and cords is entirely self-contained, and in no wise depend-

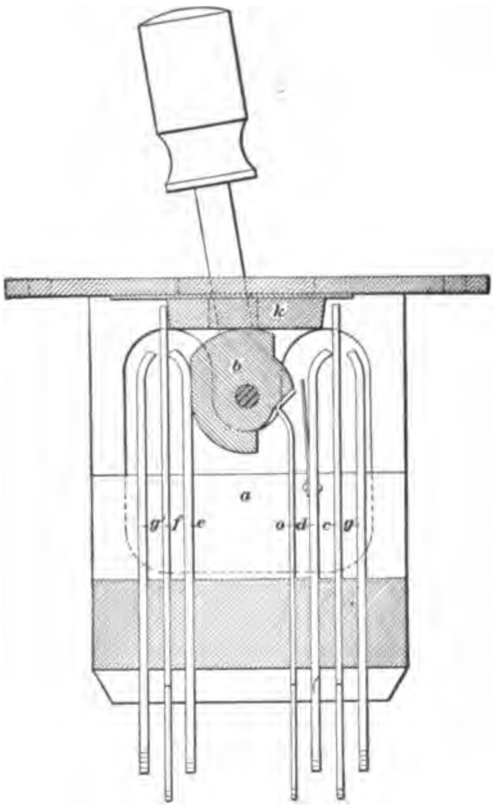


FIG. 36.

ent upon the action of the keys of the other pairs of plugs and cords. As a result, any one key may be removed bodily from the board in order to make necessary repairs, without in any way interfering with the action of the others.

86. American Ringing and Listening Key.—In Fig. 36 is shown the mechanism of a combined listening and ringing key recently put on the market by the American Electric Telephone Company. In this view of the key, the case which encloses the working parts, and thereby keeps them free from dust, is entirely removed, and a part of the framework is cut away so as to expose the working parts to view. As in the Cook key, the springs are arranged in two similar sets on the opposite sides of an insulating partition *a*. Both sets of springs, however, are acted upon by the cam *b* in exactly the same manner.

87. The circuits of this key are shown in Fig. 37, in which the two sets of springs on the opposite sides of the

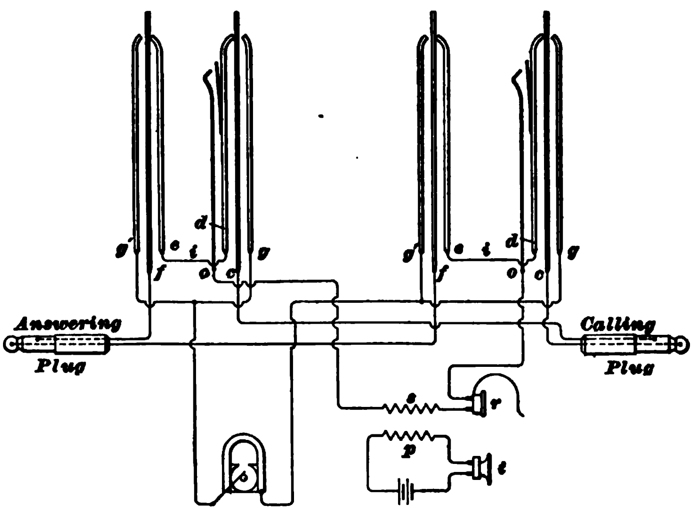


FIG. 37.

partition are removed from each other in order to show clearly the connections with the various springs in each. It will be noticed that the springs *d* and *e* on each side are permanently connected together by a wire *i*. The springs *f*, *f* form the terminals of the tip and sleeve strands of the answering plug, while the springs *c*, *c* form the terminals of the tip and sleeve strands of the calling plug. As these springs normally rest against the springs *d* and *e*, which, as we have seen, are connected together, the circuit from the tip of the calling plug to the tip of the answering plug is made complete through springs *f*, *e*, wire *i*, spring *d* and spring *c*, all on one side of the insulating partition *a*. In like manner, the circuit between the sleeves of the calling and answering plugs is normally completed through the same springs on the other side of the partition *a*.

The secondary circuit of the operator's set, comprising the secondary coil *s* and the head receiver *r*, is connected between the two springs *o*, *o*. When the lever of the key is moved to the right one step from its normal position, the springs *o*, *o* press against the springs *d*, *d*, without causing the latter to break contact with any of the other springs. This connects the operator's circuit across the tip and sleeve strands of both the cord circuits, as may be easily traced out. If the lever is pushed still farther to the right, the block *k*, Fig. 36, which slides with the lever, presses against the springs *c*, *c*, causing them to break contact with the springs *d*, *d*, and to come in contact with the springs *g*, *g*. Each spring *g* on the right is permanently connected to the corresponding spring *g'* on the left, and the two pairs of these springs form the terminals of the calling generator, as shown in Fig. 37. When, therefore, the springs *c*, *c* come into contact with the springs *g*, *g*, the terminals of the generator are connected with the terminals of the calling plug, while the answering plug is cut off, and therefore does not receive this current at its terminals. In the same manner, if the key lever is pressed to the extreme left, the block *k* pushes the springs *f*, *f* into engagement with the generator springs *g'*, *g'*, thus sending current to the answering plug and at the same time cutting off the calling plug. By this arrangement, all the switching operations are performed by the motions of a single lever, without the necessity of auxiliary buttons.

88. The key manufactured by the Western Telephone Construction Company accomplishes the same results in a different manner, the ringing on either plug being accomplished by rocking the key towards or from the operator, while the operator's telephone set is connected across the cord circuit by pressing downwards upon the lever while it is in its center position.

89. Other Forms of Ringing and Listening Devices. — It is obvious that if certain motions which are necessarily performed by an operator in making connection between two subscribers, can be made also to perform secondary functions, such, for instance, as listening in or ringing, the action of the switchboard will be facilitated. Several examples of this have already been shown in the mechanisms by which the drop of a calling subscriber is restored automatically by the insertion of a plug into the jack. Still another example was in the case of the American Electric Company's combined drop and jack, where the pushing of a plug to its fullest extent into a jack accomplished the operation of ringing the called subscriber. Many such devices have been produced, with the idea of increasing the rapidity with which switchboards could be operated, and among them is one shown in Fig. 38. This

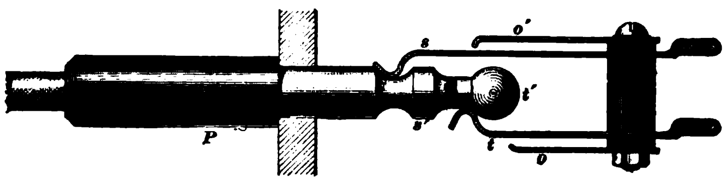


FIG. 38.

is for bringing the operator's telephone into circuit with the line of a subscriber by the partial insertion of a plug in, or its partial withdrawal from, a jack. In this figure, *t* and *s* are, respectively, the tip and sleeve springs of a jack, which are adapted to make contact with the tip and sleeve contacts *t'* and *s'*, respectively, of a plug *P*. The springs *o* and *o'* form the terminals of the operator's telephone set, and are arranged in close proximity to the tip and sleeve springs in the jack. These springs *o* and *o'* may be composed of a comb of springs common to a strip of jacks. The plug *P* is provided with depressions on both the tip and sleeve contacts, into which the springs of the jack fall when the plug is fully inserted. When, however, the plug is partially inserted, the tip and sleeve springs are forced by the enlarged portions of the plug contacts into engagement with the operator's springs *o* and *o'*, thus connecting the operator's telephone across the circuit of the lines. It is obvious that to listen in, the operator has only to insert the plug a portion of the way into the jack, and after she has completed the conversation with the subscriber, she may push it entirely in, thus cutting out her telephone. If she wishes to listen in on the circuit of any two subscribers, she may do so by withdrawing the plug part way from the jack. This bridges her telephone across the circuit without disconnecting the subscribers from each other, and if she finds that the line is no longer in use, she completes the withdrawal of the plug.

90. Plug-Seat Listening Key.—Still another device for facilitating the work of the operator is shown in Fig. 39. This is a listening switch connected with the seat of the calling plug. It is so arranged that when the plug is tilted in its seat, as indicated by the dotted lines, the springs *q* and *r* will be forced into engagement with the terminals *q'* and *r'* of the operator's telephone set; and as these springs are permanently connected with the cord circuit, this movement serves to bring about the connection of the operator's set across the two strands of the cord. In answering a call, the operator inserts the answering plug into the jack of the calling subscriber; she then grasps the calling plug, and without raising it from its seat, tilts it as shown, thus connecting her telephone set with the strands of the answering and calling plugs, and therefore with the line of the calling subscriber. Having learned the wishes of this subscriber, she simply raises the plug from its seat and inserts it into the jack of the called subscriber. The calling is performed in this case by a simple ringing key, such as is shown at *K* in the figure. When it is desired to listen in after both plugs are in the jacks, the knob *Q* may be pushed so as to bring the

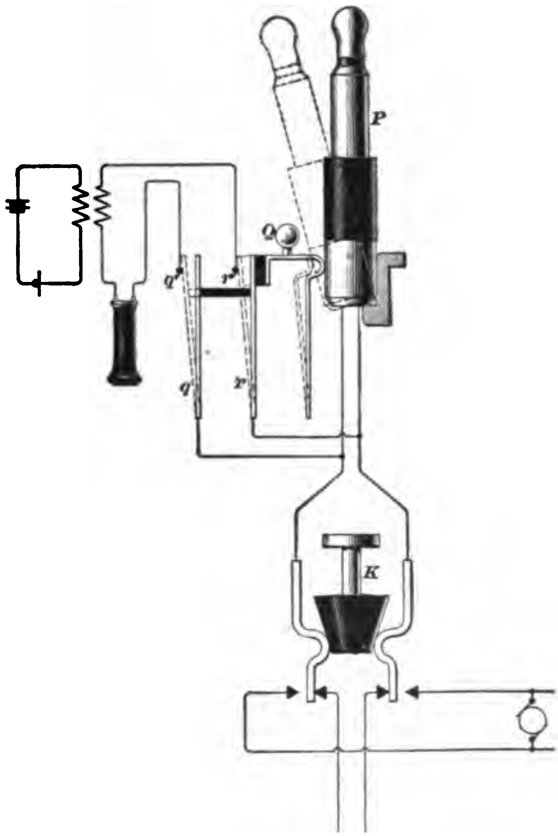


FIG. 39.

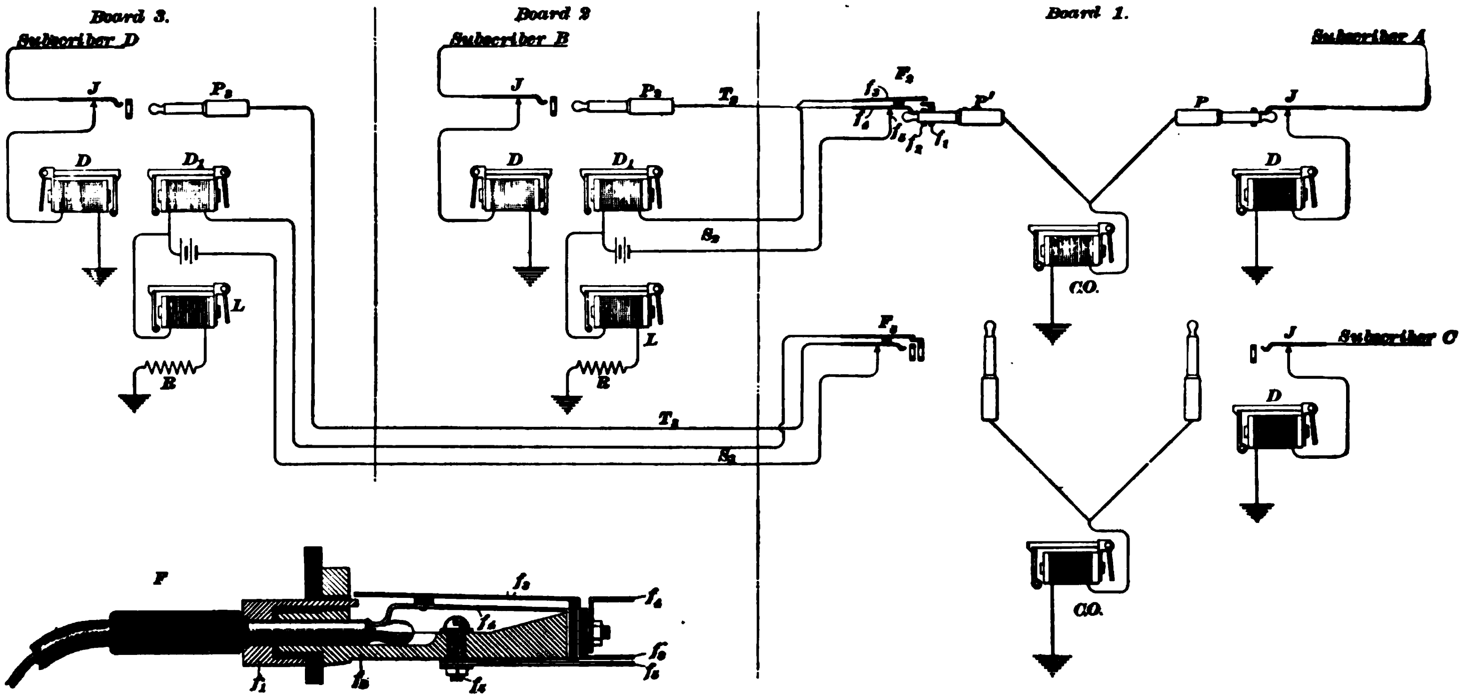
springs *q* and *r* into engagement with the contacts *q'* and *r'* respectively.

DIVIDED SWITCHBOARDS.

91. Thus far only those switchboards for use in comparatively small exchanges, that is, those exchanges having not over four or five hundred subscribers, have been described. Under ordinary circumstances, the number of subscribers allotted to a single operator during the busy portion of the day does not exceed one hundred and forty. It is obvious that any one of the subscribers whose lines terminate on the board of a certain operator may desire a connection with any other subscriber on that same section, or a connection with any subscriber on any of the other sections. Where not more than three or possibly four sections are used, the plan usually adopted, in making a connection between subscribers on different sections, is to reach across the face of the boards with the calling plug of the pair used in answering the call, and inserting it into the jack of the called subscriber. The extent to which this can be done is limited by the length of the cords, the sizes of the boards, and the reach of an average operator. The length of the cord is necessarily limited by the height of the switchboard above the floor, unless some special arrangement of pulleys is used for taking up the slack in the cords. Complication in the cord weights has, however, been found undesirable, as the room occupied by the cords is usually crowded even under the most favorable circumstances, and the added complexity is a great disadvantage.

92. Trunk Lines.—When the number of sections becomes so great that it is not economical to reach across with a pair of cords in order to complete a connection, other means have to be provided. One of these is to provide a system of auxiliary circuits, usually termed trunk lines, running between the various sections of the switchboard, and provided with means by which the operator at each end may connect any one of these lines with the line of a subscriber. The trunk lines thus serve as an auxiliary connecting circuit between two subscribers' lines that can not be well connected by a single pair of plugs and cords. A switchboard arranged to operate on this general principle is termed a divided switchboard, because its various sections are entirely independent of each other. It is obvious that in divided switchboards two operators are required to complete a connection between two subscribers, unless it happens that the line of the subscriber called for is within easy reach of the operator who answers a particular call. The term "divided switchboard" is used in distinction to multiple switchboard, in which each line is provided with a jack on each section of the board, so that any operator will have within reach a terminal socket for every subscriber's line coming into that exchange, and will thus always be enabled to complete the connection between any two subscribers herself.

93. Simple Trunking System. — The simplest method of running trunk lines between the sections of a switchboard, and one which is very often used, especially in cases where exchanges have grown so as to be too large to be handled without trunk lines, is to run a number of lines between each of the boards, terminating these lines in spring-jacks at each end. If, then, a subscriber on section No. *1* called for a subscriber on section No. *7*, the operator at board No. *1* would insert the calling plug of the pair used in answering the call into the jack of the trunk line leading to section No. *7*, and notify the operator at No. *7* of the connection desired. The operator at section No. *7* would then insert the answering plug of a pair into the jack at the other end of the trunk line used, and the corresponding calling plug into the jack of the subscriber called for. The connection would then be established between the two subscribers by means of a pair of plugs at section No. *1*, the trunk line itself, and a pair of plugs at section No. *2*. It is evident that this connection would be effected through the use of four plugs and four jacks. In more improved systems, the number of plugs and jacks used in making such a connection is reduced sometimes to three, and in one case to two. Communication between the operators is generally made by means of separate circuits, into which an operator may switch her telephone set, in order to communicate with another operator and convey to her the desired information concerning the subscriber called for and the trunk line to be used. Such circuits are spoken of as instruction circuits, and their proper arrangement is one of the most important features connected with divided-board work.



Board 3.
Subscriber D
Board 2
Subscriber B
Board 1.
Subscriber A
Subscriber C
C.O.
C.O.
F

FIG. 40.

THE COOK-BEACH TRANSFER SYSTEM.

94. This is one of the most widely known transfer systems, and is used to a considerable extent by some of the licensees of the Bell Company. It is also used by the Sterling Electric Company in the installation of their large exchanges.

In this system, trunk lines extend from each section of the board to every other section of the board in the exchange. Hereafter, in the discussion of divided switchboards, the term "board" will mean only one section of the whole switchboard. Each trunk line terminates in a jack on the board where an original subscriber's call is to be answered, and in a plug on the board where the connection is to be completed. In connection with each trunk line is an individual signaling circuit containing an annunciator drop at the calling end of the trunk line, where the connection is to be completed, and terminating in extra contacts on the jack at the answering end of the trunk line, in such a manner that the mere insertion of a plug into this trunk-line jack will drop the annunciator shutter. The connection between a calling subscriber's line and the answering end of the trunk line is made by an ordinary pair of plugs and cords in the hands of the answering operator. The insertion of the plug into the jack of the trunk line automatically drops the annunciator shutter at the other end of this trunk line, thus attracting the attention of the operator at the board at which the connection is to be completed. This operator then communicates with the first operator in order to learn the connection desired, and having done so, inserts the plug of the trunk line into the jack of the called subscriber.

95. Arrangement of Apparatus. — In Fig. 40 is shown the general plan of the system as applied to an exchange using grounded lines; the principles involved are the same as where metallic circuits are used. Several subscribers' lines are shown terminating in three different boards of the exchange, numbered, respectively, *1*, *2*, and *3*. Each subscriber's line terminates in a spring-jack *J*, the circuit being normally completed in each case through a drop D to ground. Each operator is provided with a set of answering and calling plugs P and P', having associated with them the usual forms of circuit-changing devices for listening in and ringing, these devices being omitted from the cord circuits for the sake of clearness. At each board is also provided a number of spring-jacks F_1, F_2, termed transfer jacks, and forming terminals of the trunk or transfer lines, and also of the signaling circuits extending between the operators.

96. Arrangement of Trunk Lines. — From each board a separate trunk line runs to each other board in the exchange; that is, from board No. *1* a trunk line T_2 extends to board No. *2*; another trunk line T_3 extends to board No. *3*; similarly from board No. *2* a trunk line extends to board No. *1*, and another extends to board No. *3*, and so on throughout the exchange. Only those trunk lines extending from board No. *1* are shown, for the sake of clearness, but it must be borne in mind that boards Nos. *2* and *3* are similarly equipped with transfer jacks and trunk lines leading to the other boards. In practice, in order to give the required number of connections, it is found necessary to connect each board with every other board by two trunk lines instead of one.

The trunk lines terminate at one end in each case in one of the transfer jacks F_2 or F_3, and at their opposite ends, in plugs P_2 or P_3, the jacks F_2 and F_3 being used in each case at the originating ends of the trunk lines, and the plugs P_2 and P_3 at the ends called. For each trunk line T_2 and T_3 are provided signaling circuits S_2 and S_3, terminating in each case at the boards where their corresponding trunk line terminates. At one end, the signaling circuit S_2 terminates in springs in the jack F_2 of that trunk line, and at the other end in a drop or signal D_1, placed in proximity to the trunk-line plug.

97. Trunk Jacks.—Spring-jack F is shown in detail in the lower left-hand portion of Fig. 40, and its construction should be understood before proceeding farther. The front thimble f_1 is insulated from the frame f_2 of the jack, and has a rearwardly projecting lug, upon which a spring f_3 of the jack normally rests. The line spring f_4 normally rests upon an anvil f_5, but is pressed out of engagement therewith in the ordinary manner by the insertion of a plug. The upward movement of the line spring f_4 also causes the spring f_3 to break contact with the thimble f_1, thereby breaking the connection between them. The spring f_4 forms the terminal of the trunk line terminating in that jack. The spring f_3 forms one terminal of the corresponding signaling circuit in each case, and the anvil f_5 the other terminal of the signaling circuit. When a plug is inserted into the jack, its shank makes contact with the thimble f_1, and a moment later with the spring f_4. A little consideration will show that at this moment, and before the spring f_4 is lifted, the connection between the two sides of the signaling circuit will be made complete through the spring f_3, thimble f_1, metallic contact of the plug, spring f_4, and anvil f_5. This allows the battery in the signaling circuit to send an impulse of current through the trunk-line drop to actuate the signal. As the plug is farther inserted into the jack, this circuit is broken, because the spring f_4 is lifted from the anvil f_5, and the spring f_3 from the thimble f_1. At the same time, the connection is maintained between the trunk line and the contact at the plug through the spring f_4.

98. Operation. — The operation of the system may now be understood: Suppose that subscriber *A*, whose line terminates at board No. *1*, sends in a call; the operator inserts one of the answering plugs *P*, of which she has ten before her, into the jack, and by means of a listening key ascertains that a connection is desired with subscriber *B*, whose line terminates at board No. *2*. The operator then inserts the other plug *P'* of the pair into the jack F_2 of the trunk line T_2 leading to board No. *2*. This action causes an impulse of current to flow over the signaling circuit S_2 corresponding to that trunk line, which, by operating the drop D_1, attracts the attention of the operator at board No. *2*. By means of a separate instruction circuit, the operator at board No. *1* informs the operator at board No. *2* the number of the subscriber called for. Having learned that it is subscriber *B*, the operator at board No. *2* inserts the plug P_2 of the trunk line T_2 into the jack belonging to that subscriber's line, after which the operator at board No. *1* calls up the subscriber *B* by means of a ringing key. When either subscriber rings off, the clearing-out drop *C. O.*, bridged from the cord circuit of the plugs *P*, *P'*, is actuated. The operator at board No. *1* then withdraws the plugs, and in so doing the signaling circuit S_2 is again momentarily completed, thus throwing the drop D_1 at board No. *2*, corresponding to the plug P_2. The operator at board No. *2* therefore withdraws that plug and the lines are disconnected.

99. It sometimes happens in transfer systems that after ringing off, the connection between the two subscribers is broken at one of the boards only. This may leave the other subscriber's line without an available signal, so that that subscriber can not attract the attention of the operator, no matter how much he may ring. Such a condition as this might exist if there was no plug in the trunk jack F_2 at board No. *1*, and for some reason the plug P_2 of that trunk line were left inserted in the jack of subscriber *D* at board No. *3*. That subscriber's line drop *D* would be cut out, and he would have no means of calling central. A line in this condition is usually said to be "tied up" or "hung up."

In order to provide against this, the Cook-Beach system provides an annunciator *L* for each board connected to the signaling circuit at a point between the battery and the drop. This annunciator is grounded through a resistance *R* of 1,000 ohms. Should any line—as, for instance, that of subscriber *B*—become tied up, that subscriber, in signaling, would actuate the drop *L* over the following circuit: Line of subscriber *B*, plug P_2, trunk line T_2, spring f_4, anvil f_2 (plug *P'* being out), and over one wire of the signaling circuit through the battery, and drop *L* to ground. The operation of this drop is a sign of trouble, and the operator at once investigates as to which line is in this condition. But one drop *L* is provided on each board, it being contained in a common ground connection from all the signaling circuits leading to that board.

This system as now manufactured by the Sterling Electric Company is equipped for metallic circuits throughout. The line drops are mounted in panels in front of each operator, and the line jacks directly below them. The line drops are provided with a restoring device, which, while not automatic, is capable of giving very rapid service. Each vertical row of drops is provided with a vertically sliding push-button operating a rack, so that when raised, all the drops in that vertical row that are down will be restored. The transfer drops are directly below the line jacks, and the transfer jacks directly below these drops. The plugs are arranged on a horizontal table, as are also the levers of the circuit-changing keys. This system is giving good service in a number of exchanges of moderate size, and possesses the advantages of simplicity, both in its circuits and in its operation.

WESTERN TELEPHONE CONSTRUCTION COMPANY'S MULTIPLE-TRANSFER SYSTEM.

100. Trunk-line circuits of this system differ quite radically from the divided-board systems already described. In order that but two plugs shall be used in making a connection between any two subscribers, no matter on what section of the board their lines may terminate, the transfer plugs of a set are connected in multiple to a trunk line, to which is also connected a regular pair of answering and calling plugs, at one board. This idea, as carried out in this particular system, is shown in Fig. 41, in which *X*, *1*, *2*, *3*, etc., represent the various divided boards, each containing one hundred drops and jacks. These are arranged in sections, each containing three boards, as indicated by the dotted lines in the figure. At each end of the entire switchboard is placed a blank section X and X'. At board *4*, Fig. 41, A and B represent the regular answering and calling plugs of a pair connected together through a

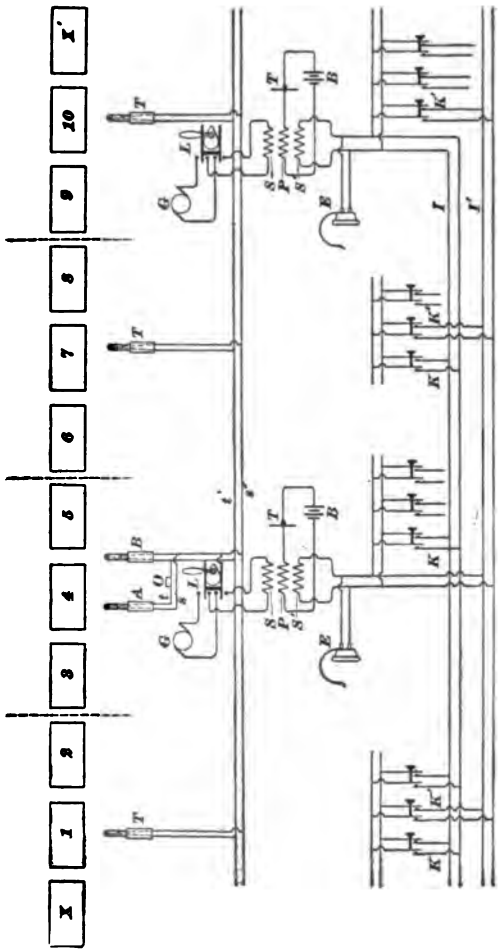


FIG. 41.

suitable circuit-changing key L, in exactly the same manner as for a small exchange. Connected with the tip and sleeve strands t and s of the cord circuit are the two sides of a trunk line t' and s', which runs throughout the entire length of the switchboard. Connected in multiple on this trunk line are transfer plugs *T*, arranged at every third board on each side of board *4*. As board *4* is the center board of the second section, it follows that every third board on each side of that will also be a center board of its respective section. The plug *A* is in each case used by the operator at board *4*, to answer any call that originates on her board. If the called-for subscriber happens to be on her own board, or on either of the boards at her right or left hand, she will complete the connection herself by the use of the regular calling plug *B*, and will call up the subscriber with whose line that plug is connected by means of her circuit-changing key in the ordinary manner. If, however, the subscriber called for is at some board not within her own reach—we will say at board *10*—she will inform the operator at the latter board of the connection desired, and of the number of the particular trunk line with which she is to complete the connection. The operator at board *10* will then pick up the corresponding transfer plug *T* and insert it into the jack of the subscriber called for, after which the operator at board *4* will send a calling current over the trunk line to the line of the called subscriber.

101. If the line of the subscriber called for had terminated at board *9*, the operator at board *4* would have informed the operator at board *10* as before, and that operator would have completed the connection with the same plug by reaching over on board *9* with her left hand; which she can readily do, as the distance between the centers of the boards is only 26½ inches. If the subscriber called for had been on either of the boards *6*, *7*, or *8*, the operator at board *4* would have given the order to the operator at board *7*, who would then have completed the connection by means of the transfer plug *T* at that board. But one trunk line is shown in Fig. 41 for the sake of clearness. It should be stated, however, that at every center board throughout the exchange there are ten pairs of

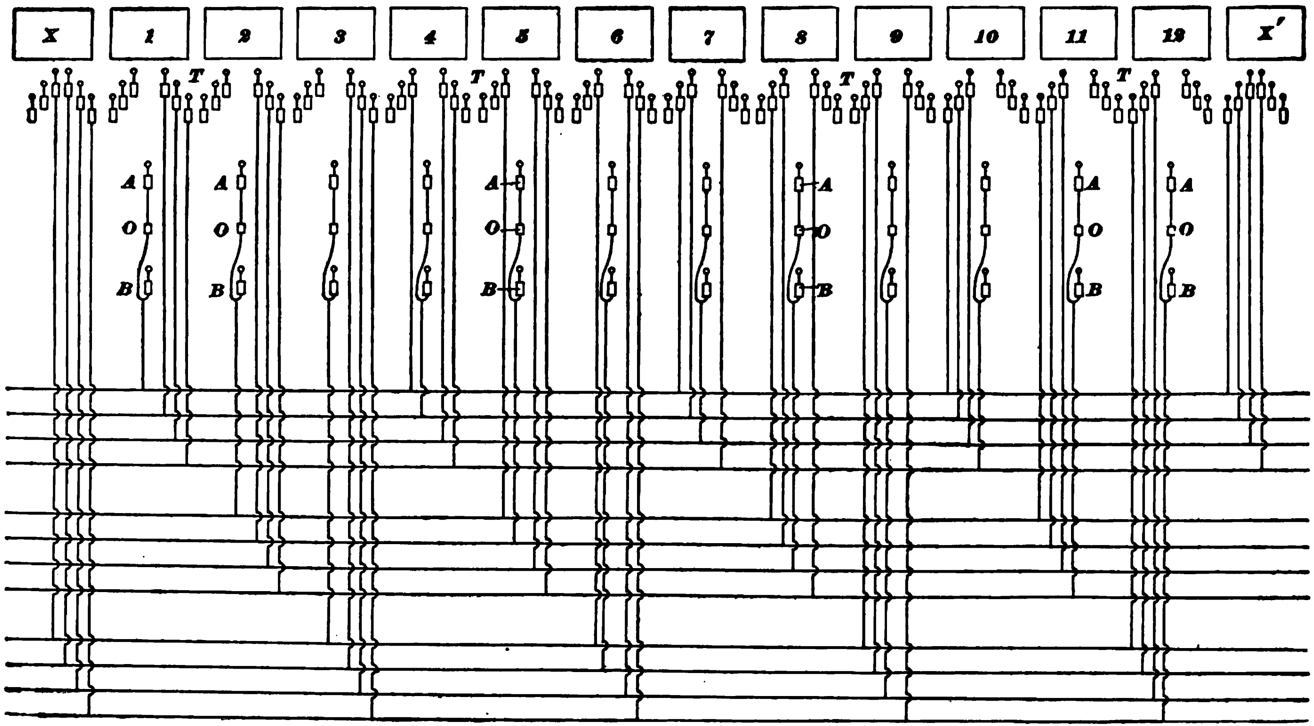


FIG. 42.

answering and calling plugs, each pair connected by means of trunk lines with ten corresponding transfer plugs at each of the other center boards. In like manner, each right-hand and each left-hand board in a section has ten pairs of answering and calling plugs *A* and *B*, connected in a precisely similar manner with ten transfer plugs at each of the other right or left hand boards of each section. A little consideration will show that at each board there will be ten pairs of answering and calling plugs and as many sets of transfer plugs as there are other sections in the exchange. In an exchange having four sections, as in Fig. 41, there would be 30 transfer, 10 answering, and 10 calling plugs, 50 in all at each board.

In Fig. 42, the connections of the trunk lines to the various plugs are shown stripped of all confusing details. The plugs *A*, *B*, and *T* correspond to those bearing the same letters in Fig. 41. Each pair of answering and calling plugs *A* and *B* is connected by means of a trunk line to transfer plugs *T* arranged at every third board from it.

102. Communication Between Operators.—Obviously the simplest way for the operators to communicate with each other for the purpose of giving orders concerning the connections would be to have them call to each other across the board, but as this would produce an intolerable confusion, a system of instruction circuits is necessarily used. The scheme on which these are laid out corresponds closely with that of the trunk lines. The operator at the center board of each section is able, by means of a push-button, to connect her telephone with that of any other center operator, but with no others. In like manner, each right-hand operator may communicate with each of the other right-hand operators, and similarly, the left-hand operators may communicate only with each other. Two sets of operators' instruction circuits are shown in Fig. 41. The operator's induction-coil has a primary winding *P* in circuit with the transmitter *T* and battery *B*, and two secondary windings *S* and *S'*, the former having its terminals in the circuit-changing key L, and the latter connected permanently across an instruction circuit I or I'. The receiver E is bridged across the terminals of the secondary coil S', so as to be affected by whatever currents flow in that coil. The operator's set shown at board *4* is connected in the manner already described with the instruction circuit I', and at every third board this instruction circuit is provided with a push-button K', the two contact springs of which are bridged across the terminals of the operator's secondary coil S', at their respective boards. In precisely the same manner, the operator's set at board *10* is connected with another instruction circuit I, which is provided with a push-button K at each of the other center boards throughout the exchange. In the same manner, all the center operators have an instruction circuit, each leading to push-buttons at all the other center boards, by which the operator at any center board may connect her telephone set with the instruction circuit of any other center operator in the exchange. What is true of the center operators' sets is also true of those of the right-hand operators and of the left-hand operators. Each is provided with an instruction circuit into which all the other right-hand operators or left-hand operators, as the case may be, may connect their telephone sets for the purpose of communication.

103. Operation of System.—When the operator at board *4* answers a call, we will say with the plug A, she connects her telephone set with the cord circuit, and therefore with the line of the calling subscriber, by means of the circuit-changing key L, in an obvious manner. This places her in communication with the subscriber, her transmitter and receiver operating in connection with the circuit of the line-wire in precisely the same manner as in an ordinary telephone. If, as has been stated, the subscriber called for is on board *3*, *4*, or *5*, the operator will complete the connection by means of the calling plug B. If, however, as is more likely, this is not the case, the operator depresses one of the buttons K, which will connect her secondary coil S' with the instruction circuit *I* of the operator who is nearest to the called subscriber's jack. This will place the two operators in communication, so that the order may be given. To illustrate this, supposing that the called subscriber was on board *9* or *10*, the operator at board *4* would depress button *K*, which would connect her telephone with instruction circuit *I*, and therefore with the operator at board *10*. Having told that operator the number of the subscriber desired and the number of the transfer plug to be used, the latter operator will complete the connection with the transfer plug *T*, after which the operator at board *4* will call up the subscriber called for by operating the circuit-changing key *L* so as to connect the trunk line with the calling generator *G*.

104. It will be seen that only two plugs are necessary in any case to complete the connection between two subscribers; but when any trunk line is in use, all the other plugs upon it which are not actually inserted into the subscriber's jack are necessarily idle and are unavailable for other use. This necessitates a greater number of plugs than would be the case were only one pair of plugs connected with the trunk line. The subscriber's line terminals, including drops and jacks, are the same in every respect as those described in Arts. **71** to **74,** inclusive, and illustrated in Fig. 27. The circuit changers are those described in Art. **88,** while the clearing-out drops are those described in connection with Fig. 12.

105. The arrangement of apparatus in this system is as follows: The section of line drops and jacks occupy spaces directly in front of each operator, and directly underneath these are placed the clearing-out drops. The plugs are arranged in two tiers, the center portion of the upper one of which is occupied by the answering plugs, and the center portion of the lower one by the calling plugs. In the spaces at the right and left of the answering and calling plugs at each board are placed the transfer plugs, each set of which is labeled with the letter of the board from which their trunk lines run. For this purpose, the boards are lettered usually from right to left, and it will be evident that board *A* will have transfer plugs leading from boards *D*, *G*, and *J*, board *B* will have transfer plugs leading from *E*, *H*, and *K*, and similarly each board will have a set of ten transfer plugs, the answering and calling plugs of which are located at the 3d, 6th, 9th, etc., boards from it.

106. End Sections.—In order to afford the operators at each end of the entire switchboard facilities for reaching the transfer plugs which would occupy boards at their right or left, respectively, were such boards present, the two end sections are left blank, so far as drops, jacks, circuit changes, etc., are concerned, but are provided with transfer plugs, following the same general scheme of arrangement throughout.

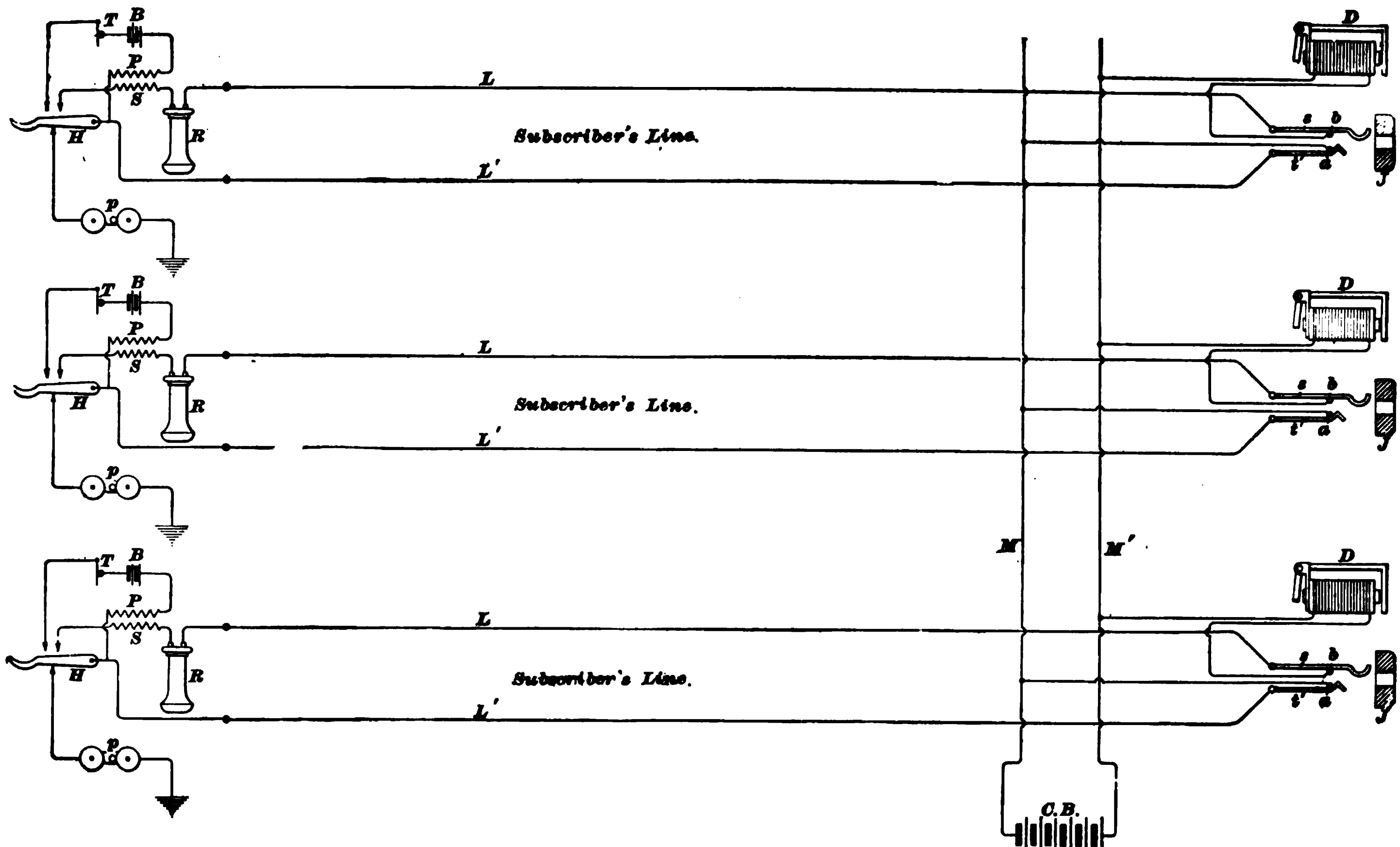
THE EXPRESS SYSTEM.

107. A transfer system which has demonstrated its ability to meet the conditions of a large exchange, in at least one instance, is that of Messrs. Sabin & Hampton, of San Francisco. This system has been in use for several years in the San Francisco exchange, and has during that time afforded means for interconnecting over 6,000 subscribers. In this system there are two classes of operators, termed, respectively, "*A*" operators and "*B*" operators, having entirely different kinds of work to perform. In like manner, there are two classes of boards, termed, respectively, "*A*" boards and "*B*" boards, and also two classes of trunk lines, termed, respectively, "*A*" and "*B*" trunks. The *A* boards are entirely removed from the *B* boards, and communication between the *A* and *B* operators is therefore brought about by telephone only.

108. Apparatus at "A" and "B" Boards.—Upon the *B* board are placed the subscribers' line drops and the jacks in which the various lines terminate. The *A* trunks, which connect boards *A* and *B*, terminate in plugs at both boards. The *B* trunks, which also connect boards *A* and *B*, terminate in plugs at the *B* board, but in jacks at the *A* board. Associated with the *A* and *B* trunks at both boards are all the necessary listening-in and signaling devices and switches whereby the operator may place her telephone set in connection with the trunk lines or with the instruction circuits leading to the other boards.

109. Brief Outline of Operation.—It may be said, in brief, that the first operation in establishing a connection between two subscribers is for a *B* operator to insert the plug of an *A* trunk into the jack of the calling subscriber. This transfers the connection to one of the *A* operators, who, by means of her listening key, places herself in communication with the subscriber and finds out the subscriber with whom he desires a connection. Having learned this, she inserts the plug of the *A* trunk used into the jack of a *B* trunk leading to the proper board, that is, to the board on which the line of the called subscriber terminates. She then instructs the *B* operator at that board to complete the desired connection, which is done by inserting the plug of the *B* trunk into the jack of the called subscriber. It is seen that every connection is necessarily handled by three operators. The first movement on the part of a *B* operator is merely to insert a plug of any *A* trunk into the jack of the calling subscriber, without listening in on the circuit or without communicating with any other operator. This movement is entirely mechanical, and involves the insertion of a plug into a jack at which a signal is displayed, and nothing more.

110. Subscribers' Line Circuits.—The circuits of this system will be considered somewhat in detail, and in order to avoid confusion, a part of them will be taken up at a time. Fig. 43 shows three subscribers' stations connected by line-wires with the central office. The most striking feature in connection with the subscribers' station apparatus is that no magneto-generator is present. When the



T
B
P
S
H
R
p
L
L'
Subscriber's Line.
D
s
b
t'
a
J
T
B
P
S
H
R
p
L
L'
Subscriber's Line.
D
s
b
t'
a
J
T
B
P
S
H
R
p
L
L'
Subscriber's Line.
D
s
b
t'
a
J
M
M'
C.B.

FIG. 43.

receiver R is removed from the hook H, the secondary coil S of the induction-coil and the receiver are connected across the two line-wires L and L', while the local circuit containing the transmitter T and battery B is closed as usual. When the receiver is supported by the hook, the line-wire L is left open at the subscriber's station, while the line-wire L' is grounded through a high-resistance polarized bell p. Each subscriber's line terminates in the central office in the springs t and s, adapted to make connection with the tip and sleeve contacts, respectively, of the plug. The two line springs normally rest upon anvils a and b, of which the former is connected directly with the battery main M, and the latter is connected with the main M' through the line drop D. The call battery $C. B.$ is permanently connected between the mains M and M', and serves as a calling battery for all the lines and drops in the exchange. Under normal conditions, no current from the battery $C. B.$ can find its way through the drops D, because the circuit between the two sides of the subscribers' lines is opened at the subscribers' stations as long as the receiver is on the hook. As soon, however, as any subscriber removes his receiver, the circuit between the lines L and L' is completed through the receiver R, secondary coil S, and hook H. This allows a current from the battery to flow through battery main M', drop D, anvil b, sleeve spring s, subscriber's line L, through the subscriber's station apparatus and back by subscriber's line L', tip spring t, anvil a, and to main M, which is connected with the other pole of the battery. Thus the mere removal of the receiver from the hook at any station serves not only to connect the subscriber's telephone apparatus with the line, but also to energize the annunciator at the central office for attracting the attention of the operator. When a plug is inserted in the jack J, the circuit from the battery is broken, because the line springs of the jack are lifted from their respective anvils.

111. Line Drops.—The drop D is of the automatically restoring type, having no pivoted shutter, as in the drops so far considered. The shutter is rigidly attached to the forward end of the armature rod, so that when the armature is attracted, the shutter is raised into the position

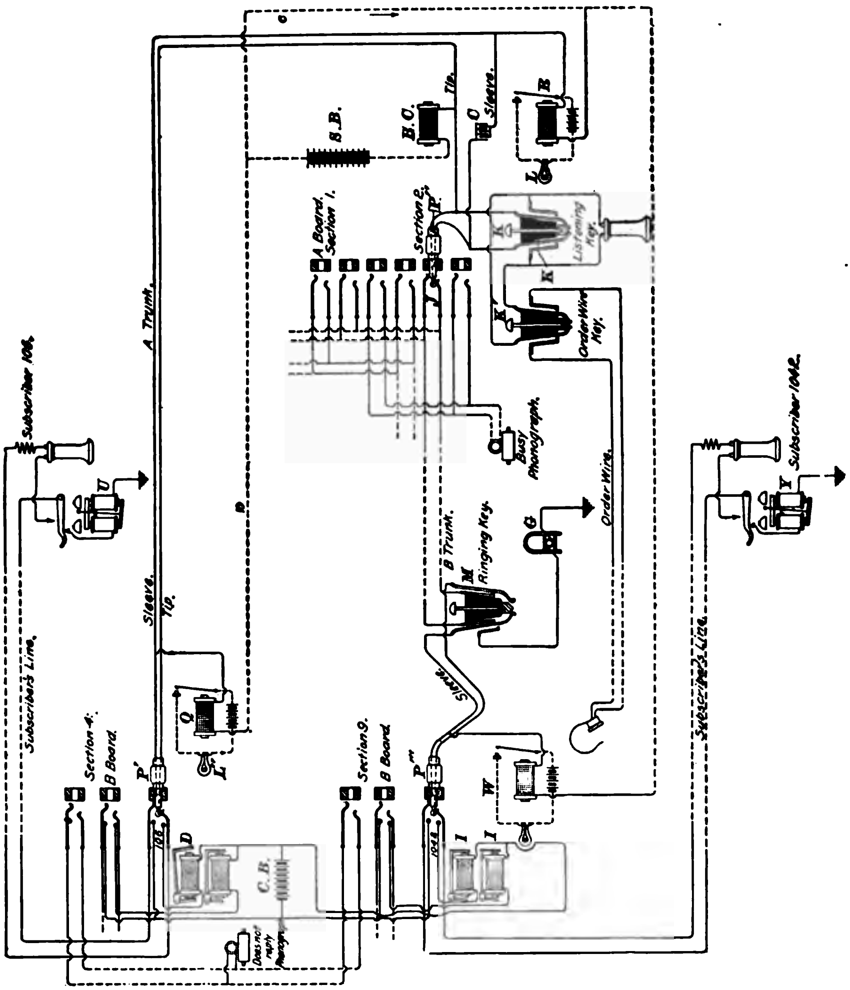


FIG. 44.

shown at *D*, Fig. 44, thus displaying a signal normally concealed behind it. It is obvious that as soon as the actuating current ceases to flow, the shutter will by gravity return to its former place, thus concealing the signal. Thus, by the very simple arrangement of circuits, the magneto-generator is entirely dispensed with. The automatic calling of central by the subscriber is accomplished, as is also the automatic restoring of the line signal, upon the insertion of the operator's plug.

112. "A" and "B" Trunks. — It has now been made clear how a subscriber signals the central office. The next point to consider is the establishment of the connection between the subscriber calling and the subscriber called for. The operations by which this is brought about will be more readily understood from Fig. 44, which shows only such portions of the apparatus and circuits as are essential in bringing about this connection. Let it be assumed that subscriber *106* desires to converse with subscriber *1042*, and that for that purpose subscriber *106* has removed his receiver from its hook and actuated his line drop, as already described. *D* should return to its normal position as soon as the plug *P'* is inserted into the jack.

The *B* boards are shown at the left of this figure and the *A* boards at the right. A single *A* trunk line is shown extending from the *B* board, in which the line of subscriber *106* terminates, to one section of the *A* board, this *A* trunk terminating in a plug *P'* at the *B* board and *P''* at the *A* board. Extending from a jack *J* on the *A* board is a *B* trunk extending to a plug on the *B* board, at which the line of subscriber *1042* terminates.

113. Ingoing and Outgoing Calls.—Inasmuch as two *B* boards will be instrumental in making the connection, a distinction will be made between them by terming the board at which the call is received the incoming *B* board, and the board at which the called-for subscriber's line terminates the outgoing *B* board, the terms incoming and outgoing referring more particularly to the calls. It must not be supposed from this, however, that these two *B* boards are in any way different, for their apparatus are in every respect the same, and the operators have the same duties to perform. Any *B* board may at one instant be referred to as an incoming board and the next as an outgoing, according to whether the subscriber's line with which a connection is being established is that of a calling subscriber or a called-for subscriber.

114. Operation of Connecting Subscribers.—Upon noticing the original subscriber's signal at the incoming *B* board, the operator at that board inserts the plug P' of the *A* trunk into the jack of subscriber *106*, and does nothing more. This causes a signal lamp L' to light and extends the circuit of subscriber *106* as far as the *A* board; but unless certain means were provided for automatically signaling the *A* operator, she would not be aware of the fact that her attention was desired upon that particular *A* trunk line. A signal *L* is automatically displayed at the *A* board as soon as the incoming *B* operator inserts the plug P' into the jack of the calling subscriber. The operation of both lamp signals *L* and L' will be explained later. Noticing this signal, the operator depresses her listening key *K*, thus connecting her telephone set across the tip and sleeve conductors of the *A* trunk and enabling her to communicate with subscriber *106*. Having learned that he desires a connection with subscriber *1042*, the connection is still further extended to the outgoing *B* board, that is, the *B* board on which the jack of subscriber *1042* is located, by inserting the plug P'' of the *A* trunk into the spring-jack *J* of the *B* trunk, which leads to the proper *B* board. The connection is then completed by the *B* operator inserting the plug P''' into jack No. *1042*, the *A* operator having informed the *B* operator of the number of the subscriber called for.

115. Signaling Circuits.—From what has been said, it is seen that the actual connection between two subscribers is a simple matter; but the operation of the signals for showing the operators at all times the condition of any circuit is one of more complexity, and is therefore somewhat harder to understand.

116. The general plan by which the automatic signals are accomplished will be best understood from Fig. 44. *R* is a relay, adapted when actuated to close the local circuit of the lamp *L*, which is placed on the *A* board in proximity to the plug *P'* of the *A* trunk. The coil of this relay is in circuit with a signal operating battery *S. B.* and a balancing coil *B. C.*, the circuit containing the three being bridged across the tip and sleeve conductors of the *A* trunk. This circuit may be traced from the tip conductor, through the balance coil *B. C.*, signal battery *S. B.*, and by signal wire *c* to one terminal of the relay *R*, the other terminal of which is connected to the sleeve conductor of the *A* trunk. It is evident that the circuit through the relay *R* and the battery will normally be open, because there is normally no connection between the tip and sleeve conductors of a trunk line. When, however, the incoming *B* operator inserts the plug *P'* into the jack of the calling subscriber, the circuit between the two sides of the trunk line will be completed through the subscriber's station, it being remembered that the subscriber's receiver is removed from the hook, thereby completing the circuit between the two sides of the line. The lamp *L* at the *A* board is therefore lighted as soon as the operator at the incoming *B* board inserts the plug *P'* of the *A* trunk into the jack of subscriber No. *106*. This will inform the *A* operator that her attention is demanded on the circuit of the *A* trunk to which that lamp corresponds.

117. The various operations on the part of the *A* operator in attending to this call will be better understood by considering Fig. 45, which shows in detail one set of circuits on the table of the *A* operator's board. In this figure, the tip and sleeve conductors of the *A* trunk line are shown at the extreme left, and are connected with the cord circuit of the plug *P'* through the flexible cord. These conductors are also connected with the contact springs of the listening key *K* by the wires *d* and *e*. The balance coil *B. C.*, the signal battery *S. B.*, and the coil of relay *R* are also clearly shown in this figure connected in series in a circuit bridged across the tip and sleeve conductors of the *A* trunk. The seat in which the plug *P′* rests is provided with a switch operated by the weight of the plug, as is clearly shown. The arm *l* of this switch makes contact with the point *i* when the plug rests in the seat, and with the contact *j* when the plug is removed therefrom. One terminal of the lamp battery *L. B.* is connected with the lever *l*, while the points *i* and *j* form respectively the terminals of the white lamp *L* and the red lamp *L*. The other terminals of these lamps

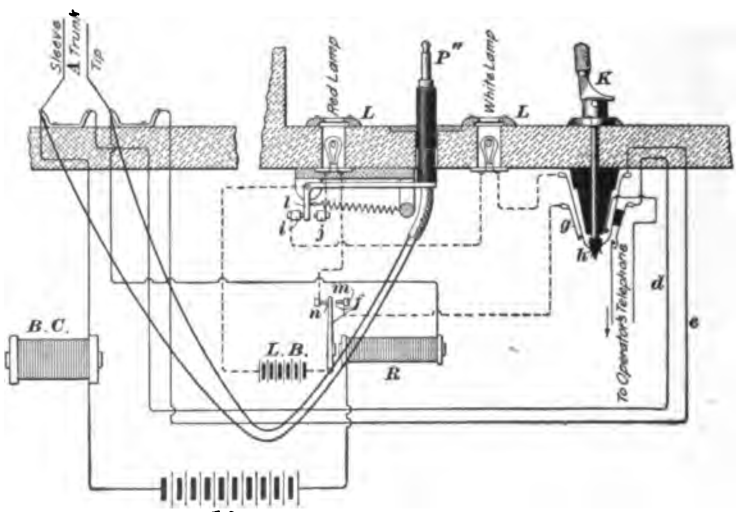


FIG. 45.

are formed, respectively, by the front and back contacts *m* and *n*, between which the armature *f* of the relay *R* plays. In circuit with the white lamp is also included a pair of contacts *g* and *h*, which are opened when the key *K* is raised by the operator pulling the handle forwards and down in listening in. The white lamp *L* is the same as that shown in Fig. 44 and already referred to. For the sake of clearness in Fig. 44, the key *K*, which is, as a matter of fact, exactly like key *K* in Fig. 45, has been simplified, and the contacts in the lamp circuit *L* have been omitted.

118. The local circuit of this white lamp may be traced from one pole of the battery *L. B.* to the lever *l* of the plug-seat switch, thence, when the plug is in its socket, to the contact *i*, through the lamp and through the contacts *g* and *h* to the back contact *m* of the relay, and through the armature of the relay to the other terminal of the battery. With the apparatus in its normal position, the white lamp will, as has been seen, be lighted when the *B* operator at the incoming board inserts the plug *P'* of the *A* trunk into the jack of the calling subscriber. It will remain lighted until one of three things happens: until the operator listens in, which will break the circuit between the springs *g* and *h*; until the plug *P'* is removed, which will break the circuit at the point *i*, or until the calling subscriber hangs up his receiver, which would deenergize the relay *R* by opening its circuit, and thereby cause it to let go of its armature. Upon seeing this lamp light up, the *A* board operator will use the key *K* corresponding to the lamp *L* to connect her telephone set with that of subscriber No. *106*. She will then be informed by him that subscriber *1042* is the party desired. The *A* operator will know at once upon what *B* board that subscriber's line terminates, and she will at once release the key *K* and depress her instruction key *K'* (see Fig. 44), thus placing herself in communication with the operator at the proper *B* board, which board will now be termed the outgoing *B* board. The *A* operator tells the *B* operator at the outgoing *B* board the number of the subscriber called for, and the *B* operator informs the *A* operator as to the number of the *B* trunk to be used. The *A* operator then inserts the plug *P'* into the jack of the proper *B* trunk, and the *B* operator, at the outgoing *B* board, inserts the plug *P'''* of the same *B* trunk into the jack of subscriber *1042*. The latter operator also depresses the ringing key *M*, which connects the grounded generator *G* with the sleeve side of that subscriber's line, thus causing his polarized bell *Y* to sound.

119. The reason why the *A* operator was required to find out from the *B* operator, at the outgoing *B* board, the number of the *B* trunk to be used, is this: each *B* trunk from each *B* board is connected with a jack on every section of the *A* board, in order that any *A* operator may have within her reach a terminal of each of the *B* trunk lines. These jacks are, therefore, connected to the *B* trunk lines in multiple, and it is obvious that two or more *A* operators might connect with the same *B* trunk line were not means provided to prevent it. The *A* operator is therefore always informed by the outgoing *B* operator the number of *B* trunk to use, and it is, of course, understood that a *B* operator will never designate a *B* trunk which is already in use.

120. Clearing-Out Signals.—In a system requiring the use of three operators to make a single connection, it is of the utmost importance that all signals between the subscribers and the operators and between the operators themselves shall be automatically given, so that no time on the part of the operators need be spent in attending to them. The clearing-out signals are of no less importance than those used for the establishment of a connection, and have been given the attention that they require in this system.

121. At the *A* board the apparatus has already been described, and it should be carefully noted that when the *A* trunk plug *P'* was placed in the jack, the lever *l* was brought into contact with the contact *j*, thus connecting the circuit of the lamp battery *L. B.* to the red lamp *L.* This circuit, however, is held open because the relay *R* is holding its armature *f* in contact with the point *m*, by virtue of the circuit already traced through the coil of the relay and the battery *S. B.* When the calling subscriber hangs up his receiver, the circuit between the two line-wires will be broken, and thus the connection between the tip and sleeve conductors of the *A* trunk will be broken. This will open the circuit through the coil of the relay *R*, causing it to release its armature, which will fly back and make contact with the spring *n*. This will complete the circuit of the lamp battery *L. B.*, through the red lamp *L*, which will attract the attention of the *A* operator and convey to her the information that the connection on that line is no longer desired. She will therefore remove the plug *P'* from the jack and replace it in its seat, which latter action will cause the lever *l* in the plug-seat switch to break contact with the point *j* and open the circuit of the red lamp. Both the circuits of the red and white lamps will then be open, the former at the point *j* and the latter at the point *m* of the relay *R*.

122. The disconnecting signal at the incoming *B* board will be accomplished by apparatus not yet described, but very similar in its action, though less complex than that at the *A* board. *Q* is a relay similar to the relay *R*, but provided with only one contact. This relay is included in series with the battery *S. B.* in the wire *o*, which wire, it will be seen, is in multiple with the wire *c* containing the relay *R*. It therefore follows that the relay *Q* will be actuated whenever the relay *R* is actuated, it being in a circuit bridged between the tip and sleeve conductors of the *A* trunk. The circuit of the relay *Q* is completed through the following circuit: wire *o*, battery *S. B.*, balancing coil *B. C.*, tip strand of the *A* trunk, receiver circuit of subscriber *106*, sleeve strand of the *A* trunk and relay *Q*. The lamp at the relay *Q* will therefore be lighted as long as the calling subscriber's receiver is removed from its hook during conversation, and will be extinguished when it is placed upon its hook, due to the deenergization of the relay magnet *Q*, which will let go of its armature at the same time and for the same reason that the relay *R* releases its armature. The going out of this lamp will show the incoming *B* operator that a disconnection is desired, and she will therefore, without further information, draw the plug *P'* from its jack.

123. The clearing-out apparatus at the outgoing *B* board is shown in Fig. 46. In this figure, the ringing key *M* is shown more in detail than in Fig. 44. Under ordinary circumstances, the two sides of the *B* trunk line are connected with the tip and sleeve strands of the *B* trunk plug *P'''* through the pairs of springs of this key. When, however, the key M is depressed, this connection is broken, and the spring p makes contact with the anvil q, and the circuit of the grounded generator G is connected with the sleeve strand of the cord, and the subscriber's bell is caused to ring, as already described. This key also carries two other contacts, r and s, which complete a circuit through the relay magnet U. When the key is depressed for ringing, this causes the magnet U to move the armature u' into the position shown by the dotted lines at the left. As soon as the circuit through this magnet is broken at the points s, r,

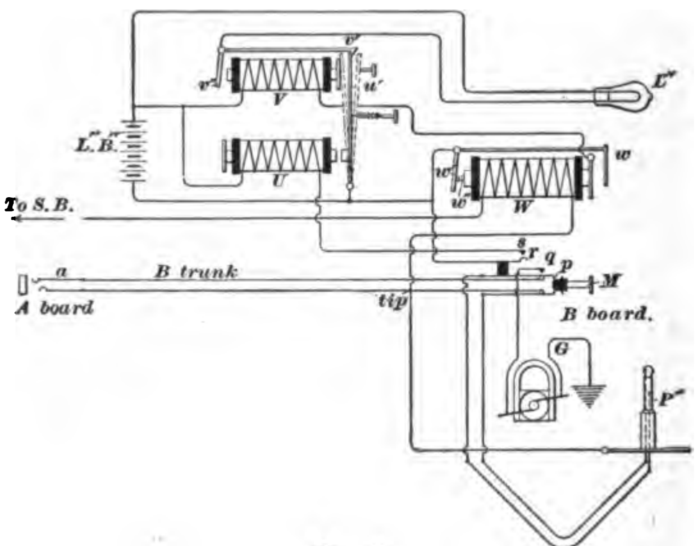


FIG. 46.

by the releasing of the key M, the armature u' falls back against the catch v', which is controlled by the armature v'' of the magnet V. The tip of the armature lever u' is platinum-pointed, as is also the catch v', and when in contact, as in the position shown by the full lines, they complete the circuit through the lamp L'' and the battery $L.''B.''$, thus lighting the lamp. This lamp will remain lighted until the subscriber called for removes his telephone from its hook, which action will close the circuit of the relay W, through the battery *S. B.* and the balance coil *B. C.*, in exactly the same manner as the circuits of the relays *R* and *Q* were closed.

124. This circuit may be quite readily traced by a consideration of Fig. 44, where it will be seen that the relay *W* is connected across the tip and sleeve conductors of the combined *A* and *B* trunk. The circuit of relay *W* is completed through the following circuit: relay *W*, sleeve strand of *B* trunk, receiver circuit of subscriber *1042*, tip strand of *B* trunk, tip strand of *A* trunk, balancing coil *B. C.*, signaling battery *S. B.*, line *c*, back to relay *W*. The operation of this relay *W* will display a signal *w*, Fig. 46, and will also at the same time close contacts *w'* and *w''*. These contacts form a part of the circuit through the magnet *V*, thereby causing it to attract its armature *v''*, thus breaking the circuit at the point *v'* and extinguishing the lamp *L''*. The going out of this lamp informs the operator that the subscriber called for has responded, and the holding of the signal *w* in its raised position caused by *W* remaining energized informs her that he is still using his instrument. This state of affairs continues until the subscriber hangs up his receiver, which opens the circuit between the tip and sleeve conductors of the *B* trunk, breaks the circuit through the relay *W* and allows the signal *w* to drop into its normal position. This is a signal for the disconnection of the subscriber, and the operator therefore withdraws the plug *P'''* from the jack of subscriber *1042*.

125. The complete cycle of outgoing *B* operator's signals is as follows: Upon operating the calling key *M*, the lamp *L''* is lighted, thus informing the operator that she has called the subscriber, but that he has not yet responded. When the subscriber responds, the signal *w* is raised and the lamp extinguished. When the subscriber hangs up his receiver at the close of the operation, the signal *w* is again lowered, and the apparatus is again in its normal position.

126. Use of Phonographs.—As an additional labor saver for the operators, phonographs are made to do a large part of the talking that the operators usually do; the arrangement by which this is brought about is shown also in Fig. 44. Two phonographs are used, one of which is constantly repeating the sentence, "Busy, please call again," while the other repeats the sentence, "Subscriber called for does not reply." Each of these instruments repeats into a transmitter connected in a local circuit with an induction-coil in the ordinary way. The terminals of the secondary coil of the "busy" phonograph are connected with spring-jacks on each of the *A* sections of the board, while the terminals of the secondary coil of the "does not reply" phonograph is similarly connected with a spring-jack on each *B* section of the board. When an *A* operator finds that a line called for is busy, she merely inserts the plug P' of the *A* trunk into the phonograph jack, and the phonograph repeats its sentence to the subscriber. In a similar manner, the outgoing *B* operator may inform the calling subscriber that the called-for subscriber does not respond.

The use of these phonographs not only saves the time of the operators, but frequently prevents the anger of a disappointed subscriber from grating upon her nerves; and this is an important consideration, especially in very busy times of day, when the nerves of the operator are necessarily heavily taxed.

THE MULTIPLE SWITCHBOARD.

MAIN FEATURES.

127. In the multiple switchboard, all trunk lines between the operators are dispensed with, the primary object of the system being to so arrange the apparatus that any operator can connect the line of a calling subscriber with that of any other subscriber in the entire system without the aid of another operator. The entire board is divided into sections, each usually containing working room for three operators, and upon each section is placed, besides the annunciators and jacks of the lines, the calls of which are to be attended to at that section, the jacks connected with every other line in the exchange. The number of annunciators usually placed on one section is 200, and in an exchange having 5,000 subscribers, it follows that 25 sections of board would be necessary. Associated with each of these annunciators is an answering jack, into which the operator inserts an answering plug, in order to connect her telephone with a line upon which a call is indicated.

128. A practice quite common with the Bell Telephone Companies in large cities is to divide each section into three operators' positions, with an operator at each position during the busy part of the day. Each operator can reach over one division on each side of her own.

In the branching switchboard made by the Western Electric Company there are fifteen pairs of plugs, one listening and two ringing keys for each plug circuit, and a jack for each subscriber's line entering the exchange at each operator's position. Room is provided for 100 annunciators and the corresponding answering jacks at each position, although seldom more than 60 to 75 are installed and in use.

On the common battery multiple switchboards which the Bell Company have just recently installed, each operator attends to the lines of 140 subscribers, a great increase over the number per operator's position customary even with the self-restoring annunciator board, which runs from 60 to 75. With the common battery board, the supervision over the lines in use and the number of movements required of each operator is considerably reduced, thus reducing the cost of operation as well as the initial cost of the switchboard by being able to reduce the total number of sections almost one-half.

In order to have the arrangement of the multiple jacks the same at each section, and also to have the answering jacks conveniently located near their respective annunciators, it is usual to have the answering jacks duplicated at each operator's position. So there are in the case cited above 140 jacks more at each position than there are subscribers' lines entering the exchange in addition to other jacks required for trunk lines to other parts of the exchange.

129. Multiplicity of Jacks.—In order that a jack connected with every line in the exchange may be within the reach of every operator, it follows that there must be a separate jack upon every one of the sections for every one of the 5,000 lines. Thus, upon each section having 200 answering jacks there would be a total of 5,200 jacks, making a grand total for the entire exchange of 130,000 spring-jacks. When it is considered that in modern exchanges the connection of each one of these jacks involves the making of five or more soldered connections, and that the wire and other materials and apparatus necessary are increased accordingly, it will be appreciated that the increase in expense over the transfer system is enormous. It may be stated that this increased expense has in most cases seemed justifiable in the best exchanges the world over, in view of the greatly increased efficiency of service.

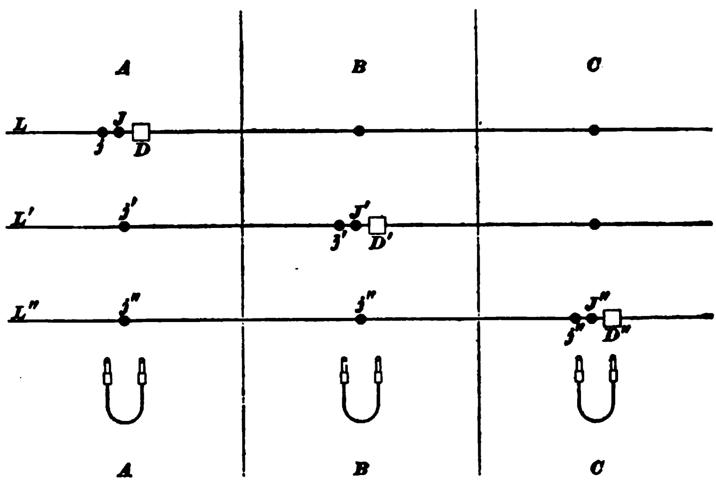


FIG. 47.

130. An idea of the general plan of a multiple switchboard may be obtained from the simple diagram shown in

Fig. 47, in which L, L', and L'' represent three subscribers' lines, each passing through jacks j, j', and j'' on the various sections A, B, and C of a multiple board. The drop D and answering jack J of line L are located at section A, and in like manner, the lines L' and L'' are equipped with answering jacks J' and J'' and drops D' and D'' at sections B and C, respectively. If the subscriber L sends in a call, his drop D will attract the attention of an operator at section A, who will answer it by inserting one plug of a pair into the answering jack J at that section, and finding that the connection desired is with line L' or L'', will insert the remaining plug of the pair into the jack j' or j'' of the line wanted. It is not difficult to understand that inasmuch as every line throughout the whole exchange is provided with a jack on section A and on every other section also, the operator at A will have means within her own reach of connecting the line L of the calling subscriber with any other subscriber's line coming into that exchange.

131. The Busy Test.—In order to understand the necessity for a busy test in multiple-switchboard systems, assume the lines L and L' to be connected together at the central office, as just described. Suppose that while they are so connected, subscriber L'' sends in a call. His drop D'' at section C will be thrown, and the operator at that section will place herself in communication with him by inserting the answering plug of a pair into the answering jack J'' of his line. Suppose, further, that this subscriber desires to be connected with line L'. It is evident that the operator at section C will, unless special means are provided, have no means of knowing that the line L' is already connected with another line at another section of the board. Should she therefore connect the line L'' with the line L', the three subscribers would be connected together and much confusion would result. In order to prevent an operator from making connection with a line which is already in use at another board, there is employed the so-called busy test, which forms an essential feature in every multiple switchboard.

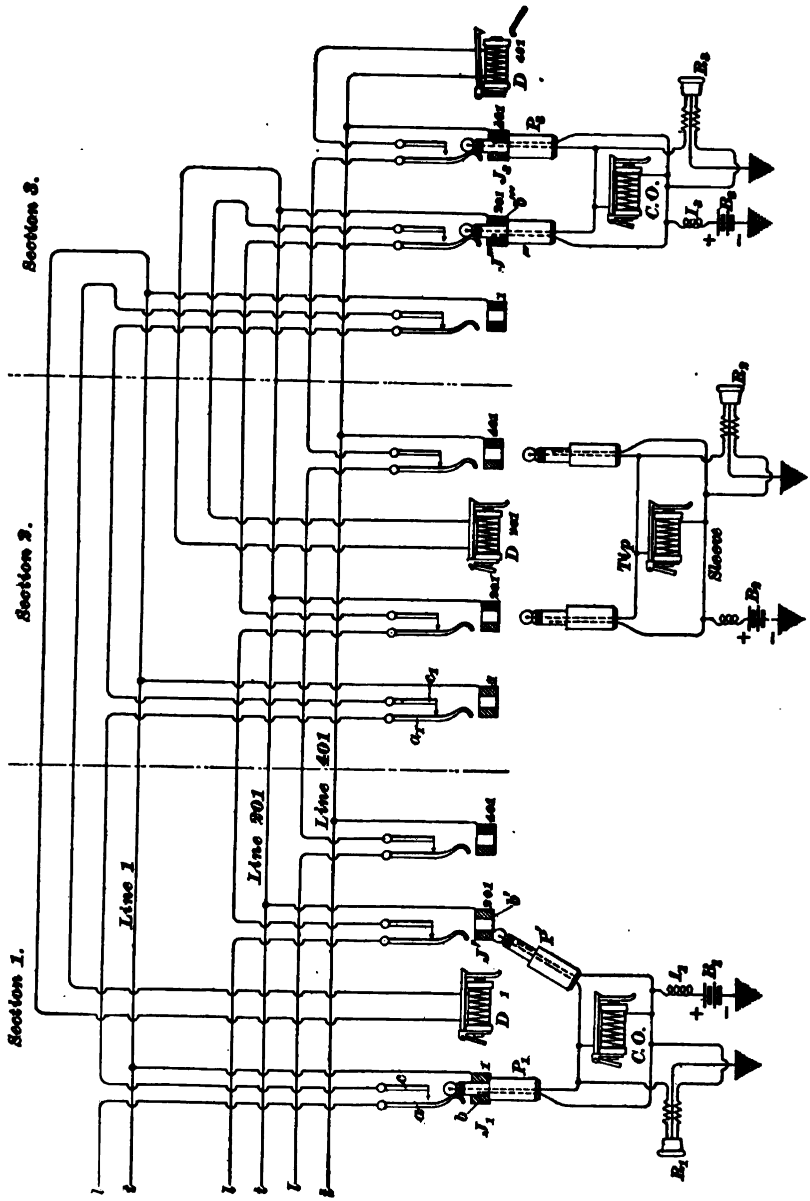

Section 1.
Section 2.
Section 3.
Line 1
Line 301
Line 401
C.O.
C.O.
D 1
D 401
Sleeve
Tip

Fig. 48.

132. The test for a busy line is usually performed by the operator applying the tip of the calling plug of a pair, or test plug, as they are termed in multiple switchboards, to the thimble of the jack of the subscriber called for. If the line is busy, she will hear a click in her telephone, while if it is free or disengaged, silence will inform her to that effect. In some exchanges, this order is reversed, a click indicating a free line and silence a busy one, but this is unusual. The details of the busy test can only be understood in connection with the complete circuits of a multiple switchboard, which will be next considered.

THE SERIES-MULTIPLE BOARD.

133. Circuits.—In Fig. 48 is shown diagrammatically three line circuits passing through sections of a multiple board. If there are 100 annunciators and corresponding answering jacks at each section, then the annunciator *D-1* and answering jack J_1 for line *1* would be located at section *1*; annunciator *D-201* and its corresponding answering jack *201* at section *2*, and so on, as shown in the figure. Of course there would be 99 more annunciators and answering jacks at each section, and in addition one jack for each line coming into the exchange at every section. For the sake of clearness, only three lines are shown. Such an arrangement of circuits as that shown in Fig. 48 represents what is termed the series-multiple board, the term series being derived from the peculiar way in which the lines pass through the spring-jacks at the various sections. The side *l* of the line *1* passes to the line spring *a* of the spring-jack at section *1*, thence to the anvil *c* upon which this spring rests, and by a continuation of the line-wire to the spring a_1, and to anvil c_1 of the jack at section *2*, and so on through a jack at each section to one side of the line drop *D-1*. The other side *t* of the line passes unbroken through each section of the board to the other terminal of the drop, and is connected with the sleeve contact *b* of each jack belonging to that line. One pair of operator's plugs connected by a cord circuit is shown in this figure at each section. The cord circuit is of greatly simplified form, and is intended to illustrate the principles rather than the actual arrangement of parts. The sleeve side of the cord circuit, at section *1*, for instance, is connected through an impedance coil I_1 to one terminal of a test battery B_1, the other terminal of which is grounded. The operator's telephone set R_1 is represented as being connected between the tip-strand side of the cord circuit and the ground.

When a subscriber (say No. *1*) sends in a call, the current from his generator passes over the line-wire *l* to the spring *a* of the first jack, then to the anvil *c* and to the spring a_1 of the second jack, and so on through the drop *D-1* and back to the subscriber's station over the line *t*, called the test side of the line *1*. This operates the drop, and the operator answers in the usual manner. The insertion of the plug into the jack raises the spring *a* from its anvil, and thereby cuts off that portion of the line circuit which passes through the succeeding sections and the drop; and at the same time, by means of the thimble *b* and the spring *a*, the two sides of the cord circuit are connected, respectively, with the two sides of the line.

134. Test.—At each one of the three sections of the multiple board shown in Fig. 48 are located the annunciator, and alongside of it the answering jack of one subscriber, and of course one jack for each of the other two subscribers. If subscriber No. *401* turns his generator, his drop *D-401* located at section *3* falls, and the operator there inserts the answering plug P_3 into his answering jack J_3-*401*. If subscriber No. *401* asks for No. *201*, the operator, finding that line *201* is not already engaged, by a test to be presently explained, inserts the other plug P''' of the same pair into the jack J'''-*201* of that line, which is at her section of the board, and the connection is completed. The calling is done in the ordinary manner by sending a current from a generator through line *201*.

The test to find out whether or not a line is busy is performed by the operator touching the tip of the calling or test plug to the thimble *b* of the jack with which she desires to make connection. Suppose that line *401* is connected with line *201* at section *3* by the cord circuit and plugs, as shown at section *3*, Fig. 48. It is evident that one terminal of test battery B_3 will be connected through coil I_3, the sleeve of the plug P''', and thimble b''' of jack J'''-*201*, with the test side of line *201*, and, in fact, with the test side of line *401* also, and therefore to all the test thimbles of the various jacks of these two lines at all sections. This will raise the potential of the test thimbles of the busy lines above the ground by an amount equal to the voltage of the battery. Suppose now that the drop *D-1*, located at section *1*, falls. The operator at section *1* inserts the answering plug P_1 into the corresponding answering jack J_1-*1*, and having learned that subscriber No. *1* desires to converse with subscriber No. *201*, she proceeds to determine whether line *201* is engaged or free. To do this, she touches the tip of the other plug P' of the same pair to the thimble b' of the jack J'-*201*, and since line *201* is connected to line *401* at section *3*, she will obtain a click in her receiver, due to a current flowing from the test thimble b' through her receiver to ground. This will inform her that line *201* is busy, and she will communicate that fact to the calling subscriber. The circuit from the test battery, through the operator's receiver, causing the click mentioned, may be traced as follows: From the positive pole of battery B_3, through the impedance coil I_3, sleeve of plug P''', thimble b''' of jack J'''-*201*, test line *t*, thimble b' of jack J'-*201*, tip of plug P', half of receiver R_1, ground, back to the negative pole of battery B_3. If no previous connection had been made with line *201* at section *3*, or at any other section, the thimbles of that line would be at the same potential as the earth, and when the operator at section *1* applied the tip of her test plug P' to the thimble b' of jack J'-*201*, she would receive no click, and would know that line *201* was free.

135. A better type of jack for a multiple board is shown in Fig. 49. This jack insures a rubbing contact between both line-wires through the springs *a* and *c* and the tip and sleeve of the plug, respectively. Furthermore, when a plug is inserted in a jack, the drop and all the jacks of that line at all sections beyond the one where the jack is inserted are entirely cut out. Therefore, no drop, wire, or jacks beyond the jack in use are left in the circuit. In Fig. 48, the charging and discharging of the open branch by a variable current in the closed part of the same circuit often causes troublesome noises and cross-talk in the neighboring circuits in the switchboard cable. The insertion of the plug breaks the contact, as stated above, between springs *a* and *d* and between *c* and *e*, and thus avoids this trouble by opening both sides of the circuit beyond the jack. The spring *f* is permanently connected to a test wire, and when no plug is in the jack this spring connects with the thimble *b*. When a plug is inserted, the spring *f* is pushed against the grounded stop *g*. In this arrangement the test battery is connected between the middle of the receiver coil and the ground. If the line is in use at section *1*, as shown, and the tip of plug *P'* at section *2* be touched to the thimble *b'*, a current will flow in the following circuit: test battery *B'*, thimble *b'*, spring *f'*, test wire, spring *f*, stop *g*, ground, and back to test battery *B'*; and produce the busy-test click in receiver *R'*.

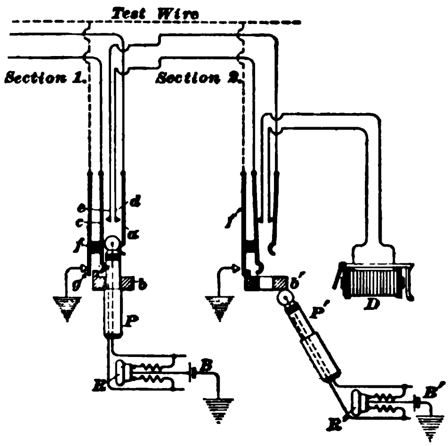


FIG. 49.

136. Cord Circuits.—Many different arrangements of cord circuits have been used with boards of this type, and the one shown in Fig. 50 is typical. *P* represents the

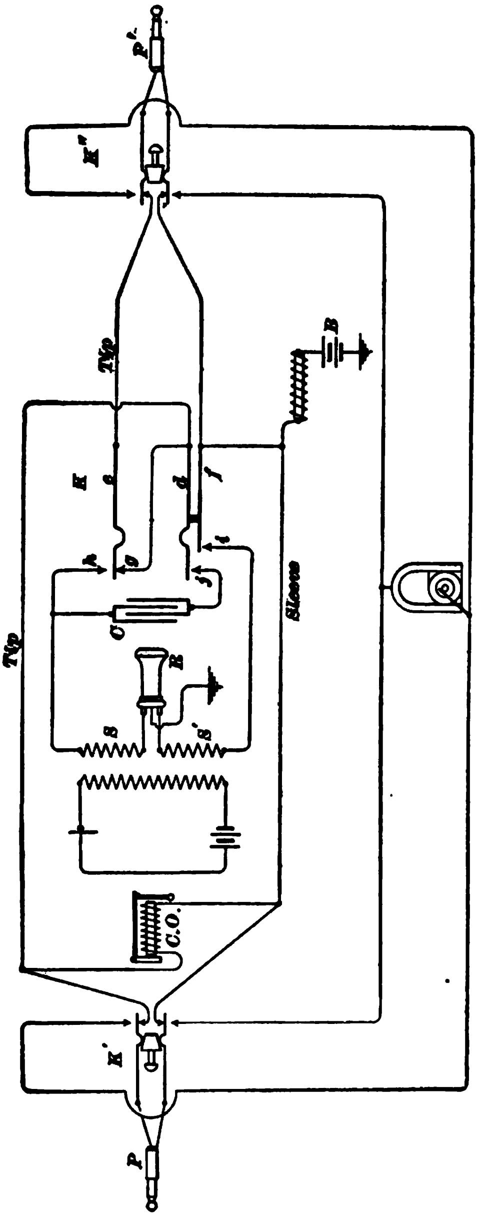


Fig. 50.

answering plug and P' the calling or test plug. K is a listening key, adapted when depressed to connect the operator's telephone set with the cord circuit. K' and K'' are ringing keys, normally preserving the continuity of the cord conductors, but adapted when depressed to connect the tip and sleeve strands of their respective plugs with the terminals of the calling generator. The operator's key K is provided with three springs d, e, and f. The spring e is connected with the tip strand of the test plug P' and normally maintains contact with the anvil g, thus completing the circuit between the tips of the answering and test plugs. This spring, when the key is depressed, is forced into contact with the anvil h, forming one terminal of the operator's telephone circuit. The sleeve strand of the cord is continuous, but is connected with the spring f of the key, which, when the key is depressed, is forced into contact with the anvil i, forming the other terminal of the operator's circuit. The spring d is permanently connected with the anvil g, and is forced by the depression of the key into engagement with the terminal j, thus introducing the condenser C into the tip side of the cord circuit. The secondary coil of the operator's telephone set is divided into two parts, S and S', contained in the circuit on each side of the receiver. The receiver coil is divided into two equal parts, the point of connection between which is permanently grounded, as shown. By grounding the center portion of the receiver coil in this manner, the balance of the line is not destroyed, as would be the case were one side of the circuit connected with the ground.

137. When the operator desires to communicate with the calling subscriber, she inserts the plug P into the jack of his line and depresses the key K. This connects the sleeve strand of the cord with one terminal of her talking set at the point i, and connects the other terminal of her talking set through the condenser C with the tip strand of the cord at the point j. This circuit is shown in simplified form in Fig. 51. The condenser C, which is included in the circuit between the calling subscriber and the operator, allows the passage of the rapidly fluctuating voice currents set up by the transmitters associated with the circuit, but prevents the flow of a continuous current over the same circuit to ground through the receiver, from the battery *B*. The operator's transmitter *T* is connected in a local circuit with a battery in the same manner as at the subscriber's station, the primary coil acting inductively upon the two secondary coils in series. The depression of the key *K* (Fig. 50), which establishes the connection between the operator and the calling subscriber, also connects the tip strand of the test plug *P'* with one terminal of the operator's telephone set,

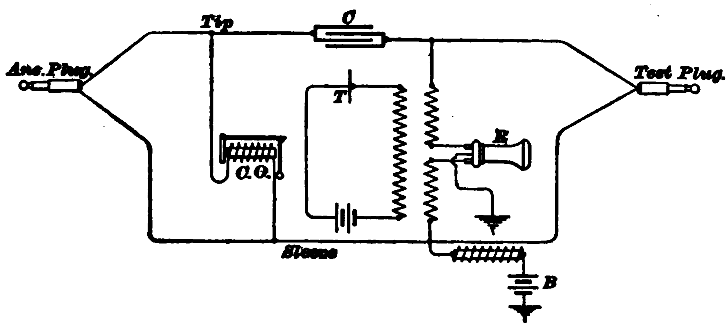


FIG. 51.

this connection being brought about by the spring *e* engaging the anvil *h*. When the operator learns the number of the subscriber called for, she retains the key in this position and applies the tip of the test plug to the thimble of the jack of the subscriber called for, to determine whether the line desired is busy or free. If the line is not in use, the thimble of the jack will not be raised to a potential above that of the ground, and therefore no current will flow to ground from the thimble of that jack through the tip of the test plug and the operator's receiver, and silence will result. If, however, the line of the subscriber called for is already in use, the thimble of its jacks will be raised to a potential above that of the ground, and a current (see Fig. 52 and **Art. 138**) will flow through the tip of the test plug, the secondary coil S, and one-half of the operator's receiver coil to ground, thus producing a click.

138. Simplified Test Circuit.—The test circuit may perhaps be more readily followed by considering Fig. 52, in which b and b' represent the test thimbles of a line which is called for, the thimble b' being that of a jack at the section where the test is to be made, and the thimble b being that of a jack of the same line which is in use, but at some other section. If the line is busy, the test battery B will be connected to the test thimble b by means of the sleeve strand of the plug at that section. When, therefore, the testing operator applies the tip of her test plug to the thimble b, a current will flow from the battery B to the thimble b, thence to the thimble b', and to ground through one of the secondary coils S and one-half of the receiver coil, and thence back to the battery B. If, however, no plug is inserted in the thimble b, it is evident that there would be no closed circuit for a current from the test battery B through the receiver, due to the application of the test plug to the jack b'

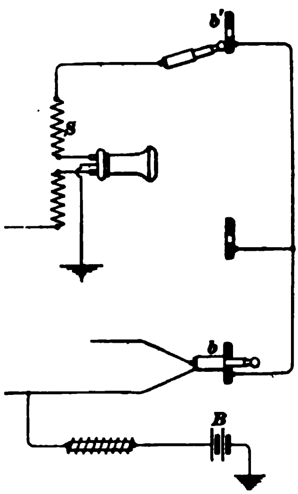
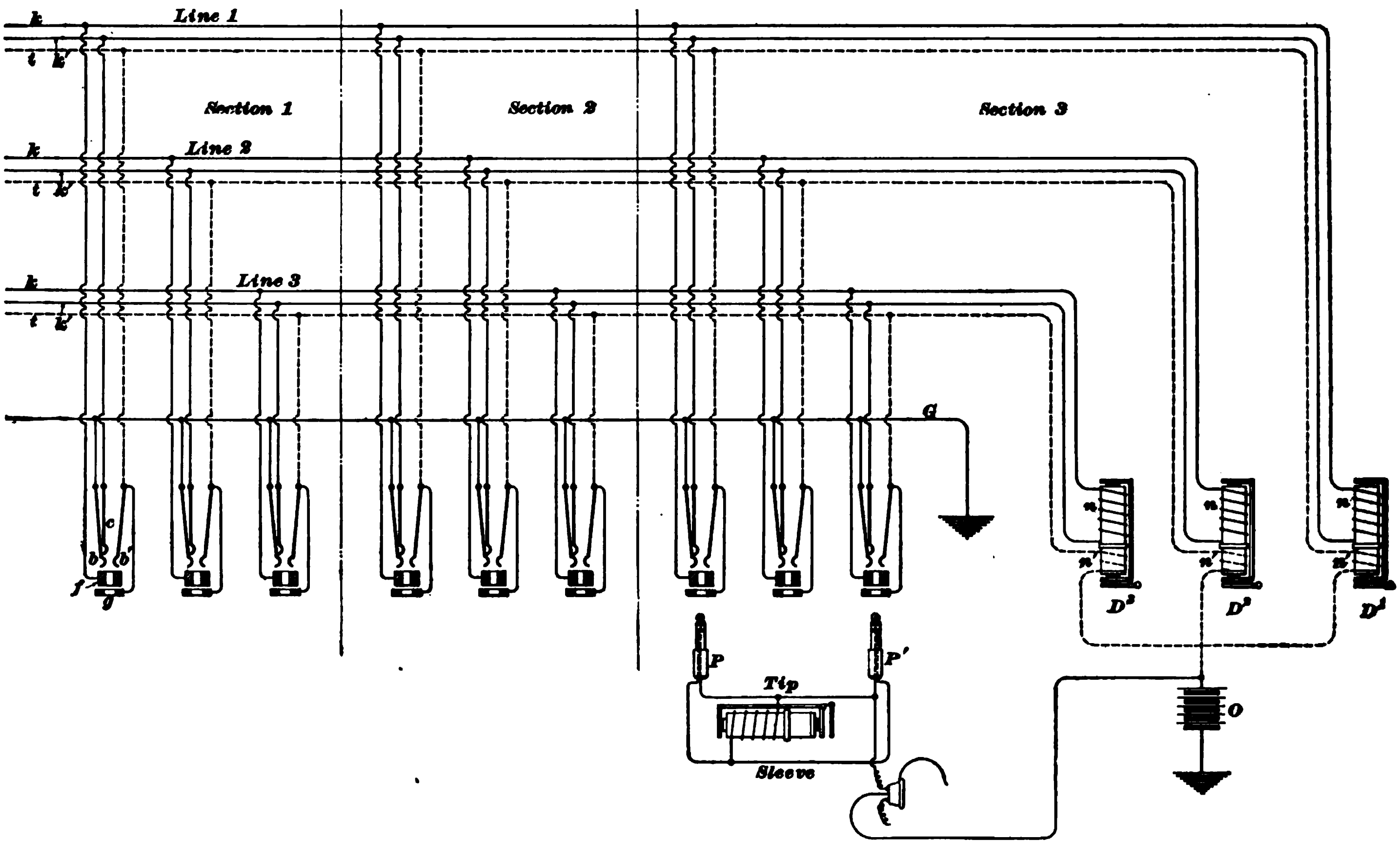


FIG. 52.

139. Reach of Operators.—The clearing-out drop is included in a bridge circuit across the tip and sleeve strands of the cord circuit, and its operation needs no description. In boards of this kind it has been customary to place the annunciators of 200 lines on each section of the board, and to provide room at each section for three operators. During the busier parts of the day, therefore, each operator would be required to answer the calls of 66 lines. It has been said that each operator has within her reach a jack connected with every line in the entire system, and it has also been stated that each section of the board is provided with a jack connected with every line. The center operator of the three at each section may readily reach all the jacks on that section, and therefore all the lines in the exchange. The left-hand operator at each section can not reach the jacks on the right-hand third of that section, but she can reach the jacks on the right-hand third of the next section at her immediate left. As these are the duplicates of those on the right-hand third of her own section, she may connect with them in the same manner as if they were on her own section. In a similar manner, the right-hand operator of each section can not reach the jacks at the left one-third of her own section, but may make connection with those on the left-hand one-third of the section at her immediate right. In this way, all the operators are provided with means for reaching every line, even though three operators occupy positions in front of each section. At the extreme right and left ends of the whole switchboard it is necessary to duplicate the jacks only of a third of a section, so the end operators of the last complete end sections shall still be within reach of all jacks.

140. Objections to the Series-Multiple Board.—The multiple board described has been widely used, but is nevertheless subject to very grave defects, and is not now being installed in new exchanges. In a system of 5,000 subscribers, there would probably be 25 sections, and the line-wire would necessarily pass in series through a pair of jack contacts at each one of these sections. A particle of dust or a loose contact in any one of these jacks would produce an open circuit, thus disabling the entire line—an occurrence which could not be easily avoided. Moreover, among other objections, this system did not lend itself readily to the use of self-restoring line drops and clearing-out signals, and therefore the work of the operators was rendered more arduous, and the amount of lines an operator could attend to was correspondingly reduced.



Line 1
Line 2
Line 3
Section 1
Section 2
Section 3
k
t
k'
G
c
b
b'
f
g
P
P'
Tip
Sleeve
n
n'
D^3
D^2
D^1
O

FIG. 58.

THE BRANCH-TERMINAL MULTIPLE BOARD.

141. Line Circuits. — This type of switchboard was designed to overcome the objections to the series-multiple board, and, it may be said, has to a large extent done so. The general arrangement of spring-jacks and drops at the various sections of the board are shown in Fig. 53, where three lines pass successively through three sections of the board, each being connected with a jack on each section and also with a drop on one of the sections. Each jack is composed of five parts: a test thimble *g*, a sleeve thimble *f* immediately behind it, a tip spring *c*, and two signal-restoring springs *b* and *b'*. The test thimble *g* is permanently connected to the spring *b'*, the two being connected by a branch wire with the test wire *t*, one of which is provided for every line in the exchange. Each of these test wires leads through a restoring coil *n'* of the drop of its line, and then passes to ground through a common battery *O*. The sleeve thimble is connected by a branch wire with the sleeve side *k* of the line, and the tip spring is similarly connected to the tip side *k'* of the line. The line coil *n* of each drop is permanently bridged across the two sides *k* and *k'* of its line, and is therefore made of high resistance and impedance. These drops are of the type shown in Fig. 25. The spring *b* at each jack is connected with the ground through a heavy wire *G*. The arrangement of the contacts in the spring-jack and those of the plug are shown in Fig. 54, in which *h* is the tip of the plug and *j* the sleeve adapted to make contact, respectively, with the tip spring *c* and the sleeve thimble *f*. These, *h* and *j*, are connected with the tip and sleeve strands of the cord circuit in the ordinary manner. A separate contact ring *i* is provided on each plug, which is entirely insulated from all other parts of the plug, and which is adapted to make contact with, and thus connect together, the two signal-restoring springs *b* and *b'* in each jack. The plug circuit is shown in greatly simplified form in Fig. 53, a clearing-out drop being connected in a bridge circuit across the tip and sleeve sides of the cords, and half of an operator's head-receiver circuit being connected between the tip side of the cord circuit and that pole of the battery *O* which is not grounded. Of course the operator's telephone is arranged to be bridged across the

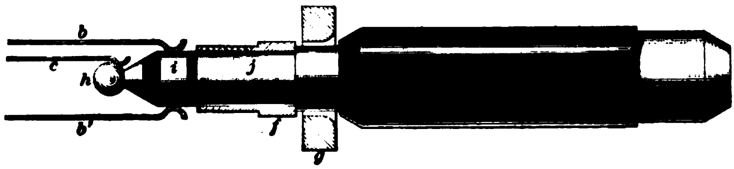


FIG. 54.

cord circuit by means of a key, it being shown connected as in Fig. 53 for the purpose of simplifying the explanation of the test circuit.

142. Operation.—If the subscriber on line *1* desires a connection, the drop D^1, the coil *n* of which is connected across his line, is thrown in the ordinary way. The operator at that section of the board then inserts the answering plug *P* into the jack of that line. This connects the tip and sleeve sides of the cord circuit with the tip and sleeve sides of the line, respectively, and the operator is, by means of her listening key, enabled to bridge her talking set across the cord circuit and communicate with the subscriber.

143. Test.—The insertion of the plug into the jack, besides connecting the cord circuit with the line circuit, brings about two other useful conditions. It grounds the test wire *t* belonging to line *1*, and therefore each one of the test thimbles *g* of all the jacks on that line. This grounding is accomplished by the connection of the springs *b* and *b'* through the ring *i* of the plug; the circuit from any test thimble on that line to ground being traced from the thimble *g* to the test wire *t*, thence to the spring *b'* at the board where the plug is inserted, through the ring *i* on the plug to spring *b*, which is grounded through the wire *G*. The connection of all the test thimbles to ground, as long as a plug is inserted in any jack of the line, is for the purpose of producing a distinguishing condition on that line to enable an operator at another section to determine whether or not that line is busy.

If, while the test thimbles of a line are so grounded, an operator at another board applies the tip *h* of one of her plugs to the thimble *g* of that line at her section, a click will be produced in her receiver, due to a flow of current from the battery *O*. The circuit through which this flow takes place may be traced from the positive pole of the battery *O* through half of the coil of the operator's receiver to the tip *h* of the plug used in testing, thence to the test thimble *g* and to ground, as already explained, and back to the negative pole of the test battery, which is itself grounded. It is obvious that if the test thimble *g* of a line is not connected with the ground, no current will flow through the receiver and no click will be produced.

144. Restoring Drops.—The other condition brought about by the insertion of the plug into the jack is the establishment of a circuit containing the restoring coil *n'* of the annunciator and the battery *O*. This circuit may be traced from the positive pole of the battery through the restoring coil *n'* to the test wire *t*, thence to the spring *b'*, contact ring *i* on the plug, spring *b* to the ground wire *G*, and back by ground to the negative pole of the battery *O*. The current flowing through this circuit energizes the restoring magnet, and restores the shutter to its normal position.

145. Complete Circuits.—The circuits of this system are shown more in detail in Fig. 55. The various parts in this figure bear the same reference letters as those used in Fig. 53, and although the diagram is arranged in an entirely different manner, it will be seen that the line circuits connecting the subscriber's station with the spring-jacks and annunciators at the central office are identical with those in that figure. Two pairs of plugs and their accessory apparatus are shown in connection with Fig. 55, one pair being located at section *1* and the other at section *2* of the switchboard. It must be remembered that the two spring-jacks shown in proximity to the upper pair of plugs *P* and *P'* are

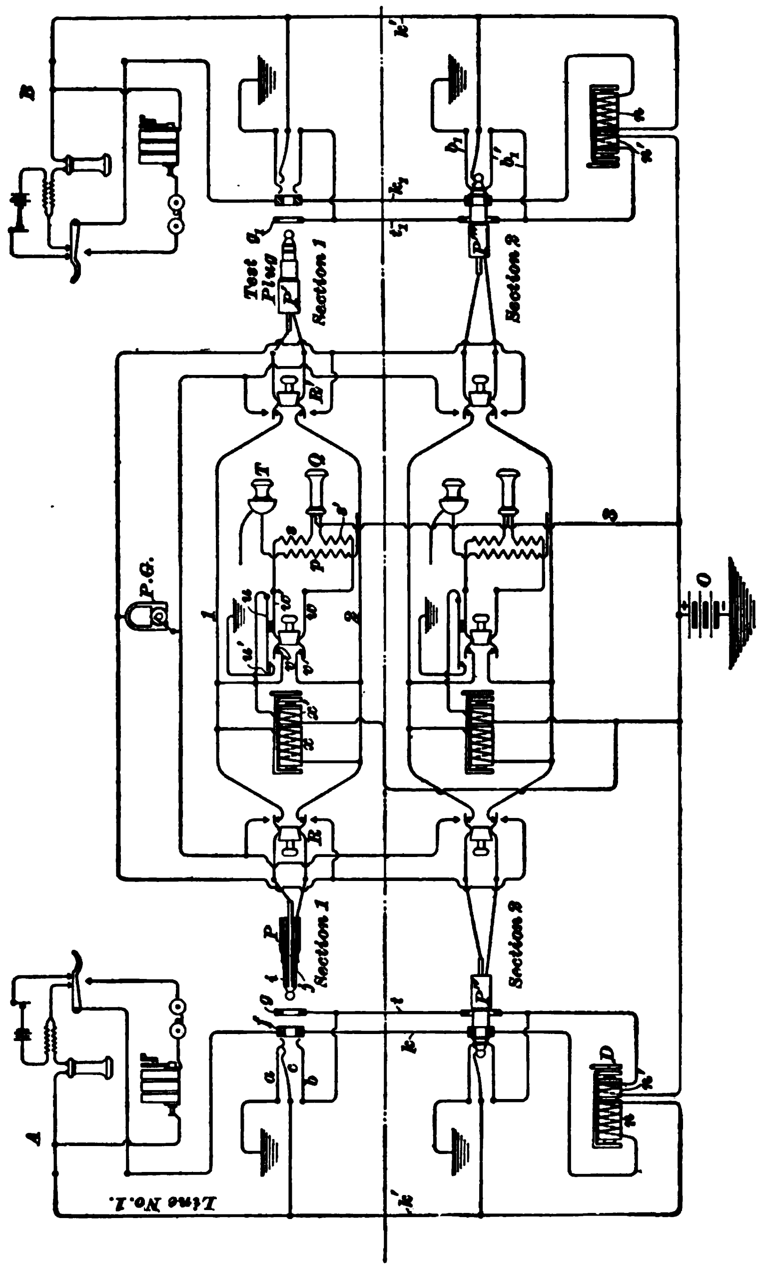


FIG. 55.

at section *1*, and those in proximity to the lower pair of plugs P'' and P''' are at section *2*. R and R' are two ringing keys, adapted when depressed to connect the circuit of the power generator *P. G.* across the terminals of the corresponding plug, at the same time cutting off the remainder of the cord circuit. Normally, however, when these keys are not depressed, the two sides of the cord circuit are continuous, the tip of the plug P being connected to the tip of the plug P' by the conductor *1* of the cord circuit, the connection between the sleeve contacts on the plug being made through conductor *2*. Across the tip and sleeve strands of each cord circuit is bridged the actuating coil x of the clearing-out drop, this coil of course being wound to a high resistance and impedance, in order to prevent the passage of the voice currents from one side of the cord circuit to the other.

146. In Fig. 53, the tip side of the cord circuit was shown grounded through half of the operator's telephone receiver, and, as was stated, it was shown in this manner for aiding an explanation of the test circuit. It is necessary for the purpose of testing that the coil of the operator's receiver should be permanently grounded through the test battery, and in order that this shall not affect the balance of the line, as it would do if the ground connection was made at the end of the receiver coil, it is made instead at the center of the coil, and the secondary winding of the operator's induction-coil is divided, one-half being connected in the circuit on each side of the receiver coil. This is clearly indicated in Fig. 55, where Q is the operator's receiver and s and s' the two halves of the secondary coil connected on each side of the receiver coil. The terminals of the secondary circuit are connected with the two springs w and w' of the listening key, which springs, when the key is raised, make contact with the anvils v and v', thus bridging the operator's secondary circuit across the cord circuit. The primary winding p of the induction-coil is connected with a transmitter T in a local circuit containing a battery, but not shown in the figure, and acts inductively upon the two halves of the secondary winding *s* and *s'* in exactly the same manner as if they were not divided. In connection with the listening key is the auxiliary spring *u*, connected with one terminal of the restoring coil *x'* of the clearing-out drop of that cord circuit. The other terminal of the coil *x'* is connected with the positive pole of the battery *O*. This spring makes contact with the grounded anvil *u'* when the listening key is raised, and thus serves to excite the restoring coil *x'* when the operator listens in. Two metallic-circuit lines, leading from the subscribers' stations *A* and *B*, are shown connected by the pair of plugs P'' and P''' at section *2* of the board. The operations by which this connection was brought about may be understood from the description already given in connection with Fig. 53.

147. We will assume now that the operator at section *1* has inserted her answering plug *P* into the jack of some third subscriber, whose line is not shown, and that that subscriber desires a connection with subscriber *B*, whose line, as we have seen, is already busy by virtue of the connection at section *2*. The operator at section *1*, however, does not know that this line is busy, and in order to ascertain its condition, she applies the tip of the plug *P'* to the test thimble g_1 of the jack on that line, while her listening key is in its raised position. Current from the positive pole of the battery *O* will then flow through the wire *3* and through one-half of the coil of the operator's receiver *Q* and one-half *s* of her secondary coil to the spring *w'* and anvil *v'*, which is in connection with the tip strand *1* of the cord circuit. From the tip of the plug *P'* the current then passes to thimble g_1 of the jack at section *1*, and by test wire t_1 to spring b_1 at the plugged jack at section *2*; here it passes through the auxiliary ring of the plug to spring b_1 and to ground, and thence to the negative pole of the grounded battery *O*. The click produced in the operator's telephone by this flow of current will inform her that the line is busy, and she will at once notify the calling subscriber to that effect.

148. Simplified Test Circuits.—The test circuit is shown, stripped of all detail, in Fig. 56, in which g_1 is the test thimble at section *1* and g' the test thimble on the same line at section *2*. The dotted line shown in connection with the thimble g' represents the ground connection which may exist by virtue of a plug being inserted into that jack, as already shown. If this ground connection does not exist, then the test thimbles and the test wire t_1 will be raised to the same potential above the earth as the tip of the testing plug *P*, this potential being due to the battery *O*, and therefore no current will flow through the operator's receiver coil when the plug tip is applied to the thimble g_1. If, however, the ground connection at g' does exist, then the potential of the test wire and test thimble will be the same as that of the earth, and current from the battery will flow through a divided path to the ground, one branch of which includes the restoring coil n' of the line annunciator, and the other of which will include one-half of the operator's receiver coil and of her induction-coil, as traced out in Art. **147**.

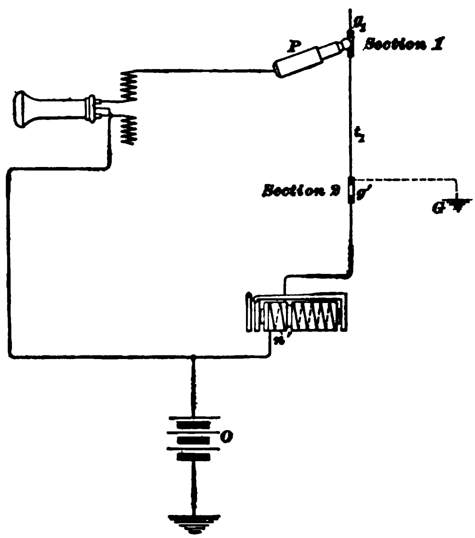


FIG. 56.

149. A study of the diagrams of this system, especially that shown in Fig. 55, will show that, with one exception, no part of the actual talking circuit established between two subscribers is at any time grounded by the operations of testing or of restoring the various shutters. The exception mentioned is due to the ground connection from the center point of the operator's talking circuit, which is connected with the line when the operator listens in. Inasmuch, however, as an equal amount of resistance and impedance is placed on each side of this ground connection, the balance of the circuit is in no wise destroyed. In order to prevent the grounding of one side of the line circuit when a plug is inserted into a jack, the thimble *g* is made sufficiently large to clear the sleeve of the plug when inserted. This is clearly shown in Fig. 54.

150. Advantages of Branch-Terminal System.—The branch-terminal system, as described, represents the highest development of the multiple switchboard, prior to the extensive use of lamp signals and centralized transmitter batteries. A complete multiple-board system, embodying these latter features, will be described later, when the lamp signals and centralized battery arrangements have been discussed. It is not difficult to see the advantages of the branch-terminal system over the series system, shown in Fig. 48, and among them may be mentioned the following: the continuity of the line circuit is not dependent upon any of the jack contacts, and, in fact, no broken contacts exist in the jacks. The balance of the line is not destroyed by grounding one side of the cord circuit, as in the series system. The use of self-restoring switchboard drops is rendered an easy matter, and lastly, the two branches of the metallic circuit of a line, which run through the entire length of the board, are always of the same length, and therefore possess the same electrostatic capacity. This latter fact is not true of the series-multiple board, because upon the insertion of a plug into the jack, one branch of the line circuit is cut off at the jack, thus leaving an open branch connected with one side of the line. This open branch extends through the switchboard cables and frequently produces cross-talk by receiving an inductive charge from another similar open branch of another line. Since the two line-wires from one subscriber run together throughout the exchange, they can be twisted together, thus avoiding, as will be explained later, all cross-talk and disturbances due to electrostatic induction from neighboring wires.

MULTIPLE-SWITCHBOARD JACKS AND PLUGS.

151. Reference to the diagrams in Figs. 53 and 55 will show that each spring-jack comprises five separate contacts, formed of three flexible springs and two stationary sleeves or thimbles. The construction of such a jack would be indeed a simple matter were it not for the fact that space must be economized to the last degree. This is rendered necessary by the requirement that each operator shall have within her reach a jack for every line in the exchange, and therefore if, as in some of the very large exchanges, the number of lines centering at one central office is 6,000, it is necessary that within the reach of every operator shall be provided that number of jacks.

152. The parts which go to make up a single jack are shown in Fig. 57 and a whole row of them in Fig. 58, in

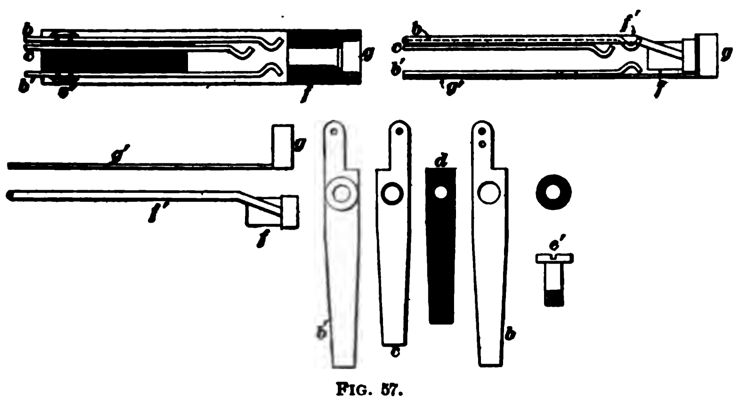


FIG. 57.

which *a* is a strip of hard rubber, properly grooved and bored to receive the contact springs *b*, *b'*, and *c* and the thimbles *f* and *g*. The hard-rubber strip *a* is of the shape shown in Fig. 58, and is of such length as to accommodate 20 jacks mounted upon it side by side. Each strip of

20 jacks is mounted horizontally in the switchboard, being secured to the frame of the board by the lugs at the ends of the strip. In the upper side of the strip are milled transverse grooves *a′* for accommodating the springs *b* and *c*, and in the under side of each strip are milled similar grooves *a″*, in which lie the springs *b′*. The grooves *a′* and *a″* extend from the rear of the strip to within about ¾ of an inch from the front of the strip. At this point they are united by a rectangular opening *a‴*, as shown. In the bottom of the groove *a′* is placed the tip spring *c*. Directly

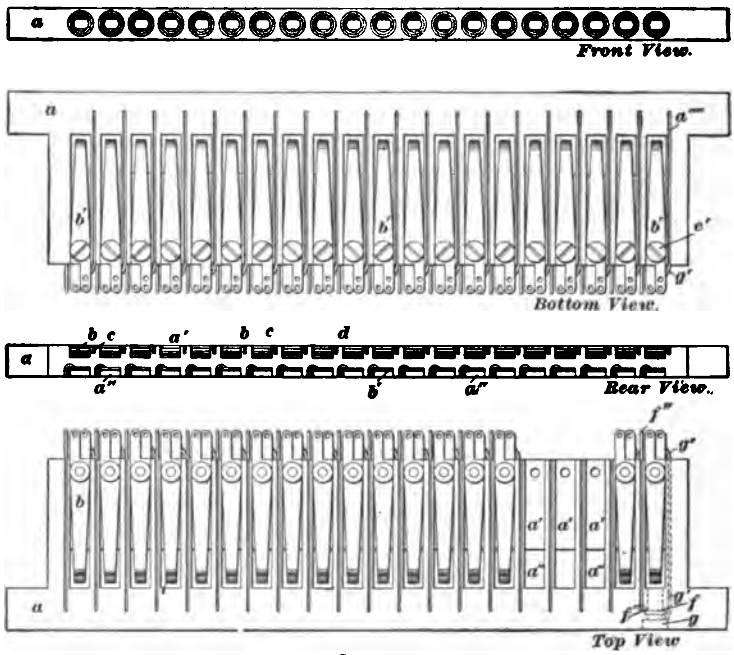


FIG. 58.

over this is laid an insulating strip *d*, shown in the details in Fig. 58. Over this strip is laid the spring *b*, its mate *b′* being placed in the groove *a″* on the opposite side of the strip. All these springs are secured in place by means of a small bolt *e′* passing through all the springs and the insulation. The springs, however, are carefully insulated from the bolt by means of a hard-rubber bushing. Holes are drilled from the front edge of the jack strip to the rectangular opening connecting the two slots, these holes being of greater diameter at the front of the strip than at the rear, for the accommodation of the thimbles f and g. The thimble f is provided with a rearwardly extending strip f', which extends through an oblique hole f'' to the upper side of the jack strip, where it follows a saw slot to the rear of the strip, as shown in the top view of the jack strip in Fig. 58. In a similar manner, the thimble g is provided with a rearwardly extending strip g', which passes through the saw slot a'''' on the under side of the jack strip to the rear of the strip. The strip g' is then soldered to the spring b', thus permanently connecting the test thimble g with that spring. The test thimble g is made of larger internal diameter than the line thimble f, in order that the plug when inserted into the jack may make contact with the line thimble only, thus keeping the test circuits entirely free from the line circuits.

153. In Fig. 59 is shown a sectional view of a plug used with the jack described in the branch-terminal system.

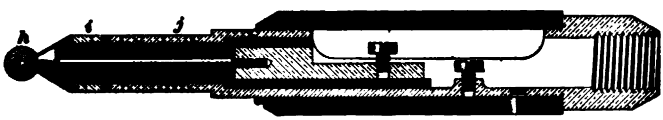


FIG. 59.

The cord connectors are clearly shown within the cavity in the handle of the plug, one of them being in metallic connection with the tip h of the plug, and the other with the sleeve j. The contact ring i on the plug is entirely insulated from all other parts, and serves, as has already been described, merely to short-circuit the springs b and b' when inserted into the jack.

TELEPHONY.

(PART 8.)

COMMON-BATTERY SYSTEMS.

METHODS OF SUPPLYING TRANSMITTER CURRENT.

1. Within the last few years, the idea of replacing all the transmitter batteries at the subscribers' stations by a single source of current located at the central station, has received much attention, and the efforts in this direction have been rewarded by so great a degree of success that now nearly all the new exchanges installed by the American Bell Telephone Company are operated upon this plan. The problem was not an easy one to solve, for although it has been occupying the minds of telephone engineers almost since the inception of the telephone, no thoroughly practical system was produced until about 1892.

BATTERY IN SERIES IN LINE CIRCUIT.

2. Grounded-Line System.—The most obvious solution of the problem was to do away with the induction-coil at the subscribers' stations, placing the transmitter and receiver at each station in series in the line-wire, the talking battery being placed at the central office in series in the circuit formed by the two connected lines. This arrangement is shown diagrammatically in Fig. 1, which represents two grounded-circuit lines, extending from the subscribers' stations and connected together at the central office through the talking battery *B*. The part of this circuit between the points *a* and *b* may be taken to represent the cord circuit, and by this arrangement a separate battery will be needed for each pair of cords and plugs. The operation in this case is that of a simple form of telephone circuit, the transmitter *T* at one station serving simply to vary the resistance of the entire circuit, and therefore to cause corresponding variations in the current flowing through the receivers *R*, *R* connected directly in the circuit. It has

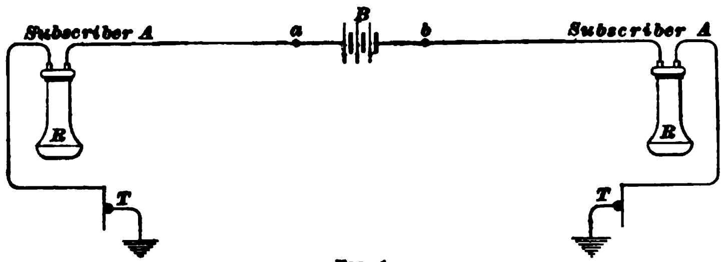


FIG. 1.

been pointed out already that this arrangement of circuits is not very efficient, because the changes in resistance produced by the transmitter bear a very small ratio to the total resistance of the circuit. It is desirable when such an arrangement is used that the resistance of the circuit shall be as low as possible, and to this end the receiver coils should be wound to a lower resistance than would otherwise be desirable. This arrangement, however, has been used, and a diagram of the circuits of a switchboard with four outlying subscribers' stations connected is shown in Fig. 2.

3. Switchboard Circuits.—The subscriber's telephone apparatus is simplified by the omission of the induction-coil, the transmitter *T* and receiver *R* being connected in series in that branch of the circuit which is connected when the hook switch is raised, and the generator *G* and ringer *C* in the alternate branch which is connected when the hook is lowered. Line-wires *1*, *2*, *3*, and *4* are connected to jacks J_1, J_2, J_3, and J_4, which are associated with the

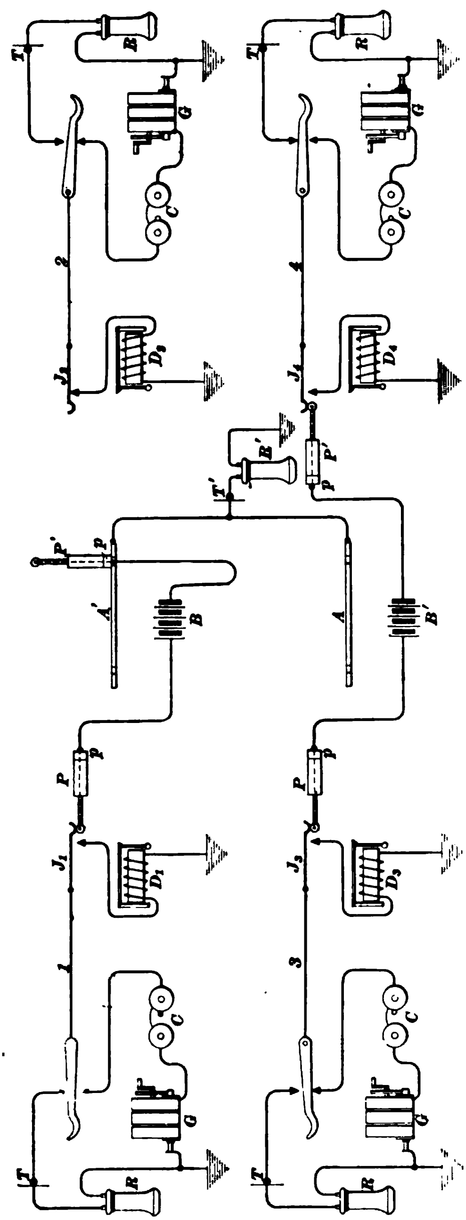


FIG. 2.

drops D_1, D_2, D_3, and D_4 in the ordinary manner. The plugs P and P' of each pair normally rest on metallic plates A, A', which plates are connected together and to one terminal of the operator's telephone circuit, the other terminal of which is grounded. This operator's circuit contains only a transmitter T' and receiver R' in series. The plugs are provided with metallic heels p, which are in electrical connection with the cords and which make contact with the metallic plates A, A' when the plugs are in their normal positions.

In Fig. 2, the plug P of the upper pair has been inserted into the jack J_1 in answer to the call of the subscriber on that line. As long as the other plug P' of this pair rests on the plate A', the operator's telephone set will be connected in series with the circuit of line *1*, the circuit being traced from ground at the central office through receiver R', transmitter T', metallic plate A, heel p of plug P', cord of plug P', talking battery B, plug P and spring of jack J_1, and through line *1* to ground through instruments T and R, at the subscriber's station. This enables the operator to communicate with the subscriber, and having learned his wishes, she inserts the plug P' into the jack J_2 of the called subscriber, this act cutting out her telephone set and connecting the two subscribers through the battery B. Lines *3* and *4* are shown thus connected by the lower pair of plugs P and P', including between them the battery B'.

4. Metallic-Circuit System.—The connection of the talking battery directly in series in the line circuits at the central office lends itself quite readily to systems using metallic circuits, provided a separate battery is used for each

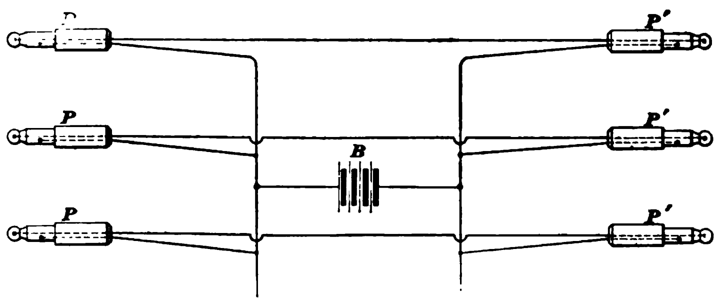


FIG. 3.

pair of plugs. The attempt has been made to use one common battery for all the pairs of plugs, by making the tip strands of the plugs continuous from the tip of the answering to the tip of the calling plug, and by terminating all the sleeve strands in the terminals of the common talking battery, this arrangement being shown in Fig. 3, in which P, P, P refer to answering plugs, P', P', P' to calling plugs, and B to the common battery. This arrangement involves the bunching together of all the sleeve strands of the answering and of the calling plugs in the exchange, and will produce cross-talk unless the resistance of the common battery and the common leads to it are made extremely low. The reason for this will be explained more fully in connection with another system, but it may be understood by considering that all the circuits formed by the various pairs of connected lines at any time are in multiple with the common battery; therefore any variation in the current flowing through one pair of lines caused by the operation of a transmitter may find circuit through the battery or through all the other lines in multiple. Unless the battery is of very low internal resistance, enough of the undulations will be shunted by it through the other connected lines to produce perceptible cross-talk. This will be explained more fully later on.

BATTERY BRIDGED ACROSS THE LINE CIRCUITS.

5. The Stone System.—One of the successful systems by which a common battery is made to serve for all the transmitters of an exchange is illustrated in principle in Figs. 4 and 5. In Fig. 4, *A* and *A'* are two subscribers'

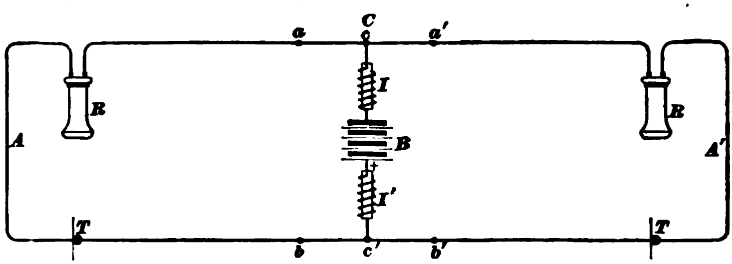


FIG. 4.

stations connected with the central office *C* by the metallic-circuit lines, as shown. The circuit of this figure illustrates the actual talking circuit between the two subscribers when they are connected at the central office by the cord circuits, the receivers *R* of each station being removed from the hook. The portion of the circuit included between *a* and *a'* may be considered as the tip strand of the cord circuit, and that portion between the points *b* and *b'* as the sleeve strand. The two metallic-circuit lines form, when thus connected, one continuous circuit, including the subscriber's receivers *R* and the transmitters *T* connected in series. Bridged across this circuit at the central office is a battery *B* connected between two impedance coils *I* and *I'*. The current from the positive pole of this battery will flow through the impedance coil *I'* to a point *c'*, where it will divide and pass to each of the subscribers' lines, and having passed through the instruments at each station, return to the point *c* where the two portions of the current unite and pass through the impedance coil *I* to the negative pole of the battery. The impedance coils are made of rather coarse copper wire wound about heavy iron cores, so that, while their ohmic resistance is very low, their impedance is very high. From this it follows that they will allow steady currents to pass through them with comparative ease, but will form a practical barrier to rapidly varying currents—such as are produced when telephoning. While the instruments at the subscribers' stations are connected with each other in series, it is clear that the two subscribers' lines are connected in multiple with respect to the battery *B* and the impedance coils *I* and *I'*. Assuming that the resistance of the two lines is the same, equal portions of current will pass through each subscriber's station. If, however, the transmitter *T* at station *A* is so operated as to increase the resistance of the line through that station, a greater portion of the current from the battery *B* will then be forced through the line of station *A'*. This is true, because the impedance coils placed in the bridged circuit with the battery tend to prevent any fluctuations in the current through them. The current flowing through the coil is therefore maintained practically constant, and an increase in resistance in one of the lines will tend to cause less current to flow through that line and more through the other. In a similar manner, if the transmitter *T* at station *A* is so operated as to decrease its resistance, the greater portion of the current will flow through the line leading to station *A*, and the smaller portion will therefore pass through the line leading to station A'. Whatever changes take place in the resistance of the circuit of one line-wire will cause corresponding changes in the current flowing in the other line-wire, and these changes in current will act on the receiver at the other station in the ordinary manner. By this arrangement, the transmitter T at one station has only to vary the resistance of the line-wire leading from the central office to that station. For short lines this system has been found to work admirably, as the total resistance of the line can be made very low.

6. Prevention of Cross-Talk in Stone System.—The battery B, as we have seen, is connected directly across the cord circuit of a pair of plugs. The use of the impedance coils renders it possible to make a single battery B

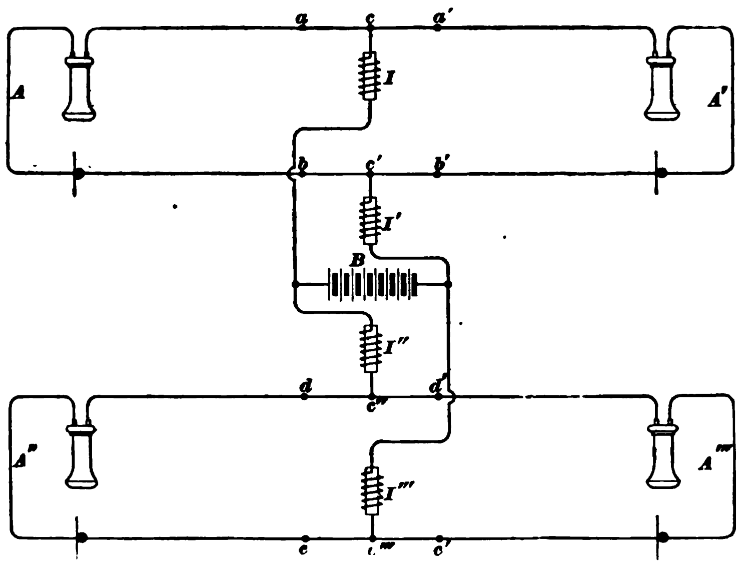


FIG. 5.

serve for a large number of cord circuits, the various leads from the points c and c' on each cord circuit being led through separate impedance coils to the terminals of the common battery. This is illustrated in Fig. 5, where two pairs of subscribers' lines are supplied by a single battery B.

The subscriber *A* is connected with the subscriber *A'* by means of the conductors *a*, *a'* and *b*, *b'* of the cord circuit. Between the points *c* and *c'* on these cord conductors is bridged a circuit containing the two impedance coils *I* and *I'* and the battery *B*, in exactly the same manner as is illustrated in Fig. 4. The subscribers' stations *A''* and *A'''* are similarly connected by the conductors *d*, *d'* and *e*, *e'* of another cord circuit. Between the points *c''* and *c'''* is bridged a circuit containing other impedance coils *I''* and *I'''* and the common battery *B*.

It might seem at first that this arrangement would produce cross-talk—that conversation being carried on between subscribers *A* and *A'* would also be heard on the lines *A''* and *A'''*, by virtue of the fact that the two circuits are connected together through the impedance coils. This, however, is not the case, for the impedance coils *I* and *I'* confine nearly all the fluctuations of current to the circuit of the lines leading to stations *A* and *A'*; but whatever fluctuations do find their way through the impedance coils *I* and *I'* can complete their circuits through two paths, one of which is through the battery *B* and the other of which is through the impedance coils *I''* and *I'''* and the combined lines of subscribers *A''* and *A'''*. The circuit through the impedance coils *I''* and *I'''* contains a large amount of impedance and considerable resistance, while the circuit through the battery *B* contains no impedance and practically no resistance; therefore the fluctuations in current which find their way through the impedance coils *I* and *I'* will be short-circuited by the battery *B* and will not pass through impedance coils *I''* and *I'''* to the lines of subscribers *A''* and *A'''*. This method of supplying current to the transmitter batteries was devised by Mr. John S. Stone of the Bell Company.

7. The Hayes System.—Another system, devised by Mr. Hammond V. Hayes, and resembling somewhat the Stone system, is shown diagrammatically in Fig. 6, in which, as in the preceding figures, *A* and *A'* are subscribers' stations and *C* the central office. *J* and *J'* are repeating coils, each having two equal windings j and j'. One end of each of the windings j and j' of each coil are connected together and to one terminal of the battery B. The other terminal of each winding of the repeating coils is connected, as shown,

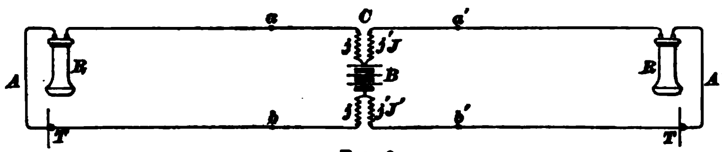


FIG. 6.

with the line-wire leading to a subscriber's station. These repeating coils are merely induction-coils, having their windings of equal resistance and the same number of turns. They are wound upon heavy, soft-iron wire cores, and in practice, the two coils J and J' are wound upon the same core.

As in the preceding figures, a and a' may be considered the terminals of the tip strand of the cord conductor of a pair of plugs and b and b' the terminals of the sleeve strand. Current flowing from the positive pole of the battery B will divide and pass through the separate windings j and j' of the repeating coil J to the line-wires leading to stations A and A'. The two portions of the current will then proceed through the instruments at this station, and back to the central office through the positive side of the line, and through the windings j and j' of the repeating coil J' to the negative pole of the battery. The action of one line circuit upon the other is probably easier to understand in this case than in the Stone system. The two circuits may be considered as entirely separate, connected inductively only through the windings of the repeating coil. If a variation takes place in the transmitter at station A, the current flowing from the battery B through the circuit of that line will be correspondingly varied. These variations will pass through the windings j, j of the repeating coils, and will therefore act inductively on the windings j', j', which are in circuit with the station A'. It is easy to see that any fluctuations in current in the circuit of station A will induce similar currents in the circuit of station A', and *vice versa*. When station A is transmitting, the coils j, j act as primary coils, j', j' being the secondary coils. When station A' is transmitting, the functions of the coils are reversed, j', j' serving as the primaries and j, j as the secondaries. As in the Stone system, the battery B may be made to serve an

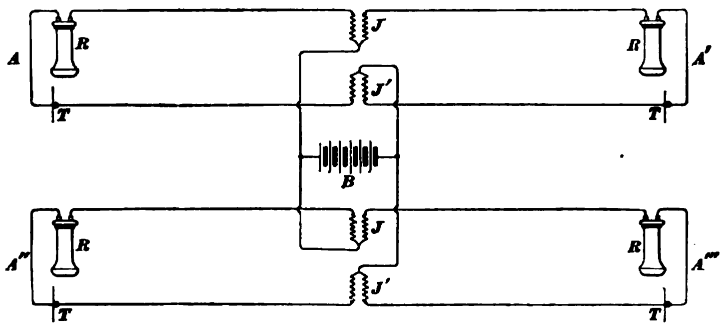


FIG. 7.

unlimited number of cord circuits, a separate repeating coil being placed between each pole of the battery and each side of the cord circuit, as shown in Fig. 7.

SYSTEMS USING INDUCTION-COILS.

8. The Dean System.—All the methods so far outlined for supplying transmitter current to subscribers' stations from a centralized battery have prohibited the use of the induction-coil at the subscribers' stations. A system shown in diagram in Fig. 8 is designed to accomplish these results and still retain the advantages of the induction-coil. In this, the stations A and A' are connected with the central office C by metallic lines, as shown. Across the cord circuit, the strands of which are represented by a a' and b b', is bridged an impedance coil I, to the center point of which is attached a wire leading to one pole of the common battery B, the other pole of which is grounded. At each subscriber's station an impedance coil I' is bridged across the line-wires, and the center point of this impedance coil is connected by wire *3* to a point *4* between the primary coil *p* and the microphone *T* in the primary circuit at the station. A point *5* on the opposite side of the primary circuit is connected by a

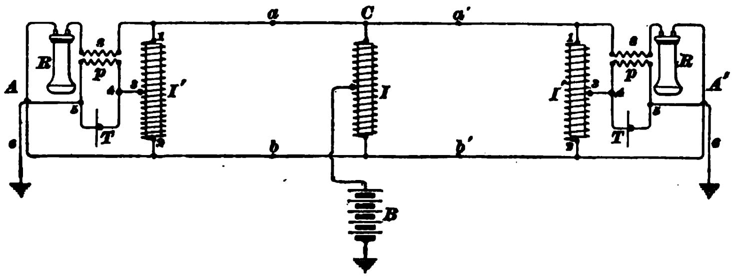


FIG. 8.

wire *6* with the ground. The secondary coil *s* of the induction-coil and the receiver *R* are connected in series in the line-wire in the ordinary manner.

9. Operation of Dean System.—When two subscribers' lines are connected together, as shown, current from the battery *B* will flow to the center of the impedance coil *I* bridged across the cord circuit where it will divide, part of it passing in multiple over the line-wires to the subscriber's station *A*, thence through the wires *1* and *2*, and the two halves of the impedance coil *I'* to its center point, where the two portions of the current unite and pass by the wire *3* to the point *4* in the primary circuit. Here the current again divides, one-half passing through the primary coil *p*, and the other through the transmitter *T* to the point *5*, where it again unites and passes by wire *6* and the ground to the negative pole of the battery *B*. In an exactly similar manner, current from the battery *B* flows through the lines to station *A'* and returns by ground to the battery. In order to understand the action of this arrangement, let it be assumed that station *A* is acting as the transmitting station and *A'* as the receiving station. Under ordinary circumstances, the current from the battery divides equally through the two branches of the primary circuit at station *A*. When, however, the transmitter *T* is caused to lower its resistance, an increased current will pass through the transmitter branch, and as a result, the current through the primary coil will be diminished. If the resistance of the transmitter is increased, the current through it will be diminished and that through the induction-coil will be increased. It thus follows that changes in the resistance of the transmitter *T* will produce corresponding fluctuations in the current flowing through the primary winding *p* of the induction-coil. These fluctuations will therefore act inductively upon the secondary coil *s*, thus causing induced currents to flow through the circuit formed by the line-wires of each of the connected subscribers, and will therefore produce the ordinary effects upon the receivers at each station. While this system is undoubtedly capable of giving good results, it has been used in but few cases, owing probably to the fact of the greater simplicity of the Hayes and the Stone systems.

Several other methods for centralizing transmitter batteries have been devised, but the ones outlined have proven their adaptability to commercial service, while the others, with some exceptions, have not.

AUTOMATIC SIGNALING.

THE LAMP SIGNAL.

10. One of the great advantages in common-battery systems is their adaptability to automatic signaling from the subscriber to the central office. The arrangement is such that no separate action on the part of the subscriber is necessary in order to transmit a signal to the central office, this result being accomplished automatically by the removal of his receiver from its hook. Hand in hand with this improvement came the adoption of the incandescent lamp for signaling purposes in telephone exchanges, the lamp presenting many advantages over the electromagnetic signals so far considered. Several arrangements of circuits have been devised for using incandescent lamps in connection with automatic signaling, one of the simplest being shown in Fig. 9, in which *1* and *2* represent the wires of a line leading from a subscriber's station to the central office.

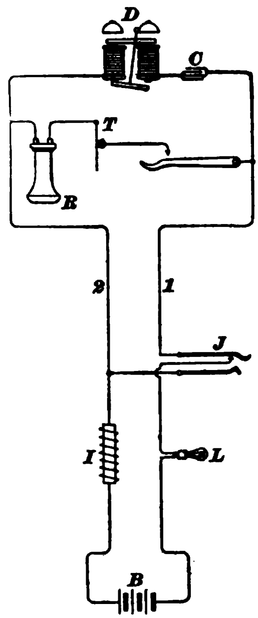


FIG. 9.

11. Lamp in Line Circuit.—The circuits at the subscriber's station are much simpler than in instruments using magnetos for calling, the apparatus being arranged in two branches: one, permanently closed, containing a polarized bell *D* and a condenser *C*, and the other, normally open, but adapted to be closed by the hook switch, containing the transmitter *T* and the receiver *R* in series. The line-wires pass to the contacts of the spring-jack *J* in the manner shown, after which they are connected together through the impedance coil *I*, the battery *B*, and the incandescent lamp *L*. When the subscriber's telephone is not in use, the circuit containing the battery *B* is open at the hook switch and at the condenser *C*, the condenser, it being remembered, forming an open circuit to steady currents, but allowing the free transmission of alternating currents. When, however, the subscriber removes his receiver from the hook, the circuit between the two sides of the line is closed through the receiver and transmitter, and as the resistance of these is low, sufficient current is allowed to flow through the circuit to illuminate the lamp *L*. When the operator plugs in, this circuit is automatically opened by the lifting of the sleeve spring of the jack from its anvil. The battery *B* is common to all the lines in the exchange, and in order that cross-talk may not result from the bunching of all the line-wires *2* at the battery terminal, an impedance coil *I* is placed in the circuit of each line between one pole of the battery and the spring-jack. The condenser *C* is often omitted, and when this is done, the bell-magnets at the subscriber's station are wound to a very high resistance, in order that the current flowing through the line from the battery *B* during the disuse of the instrument may be cut down to a minimum.

12. Disadvantages of Lamp in Line Circuit.—This arrangement of the lamp signal *L* with respect to the line, while being probably the simplest that could be devised, is subject to several serious faults and has not proved generally successful in practice. The reason for this is that it is a difficult matter to maintain the resistance of the various lines at a practically constant value, and that a lowering of the resistance—such, for instance, as would be brought about by a short circuit between the wires *1* and *2* of the line—would cause an excessive current to flow from the battery through the lamp *L*, causing the latter to burn out. The resistance of the various line circuits may be practically equalized by giving the impedance coils *I* the proper resistance; but this does not overcome the difficulty due to the changes in the resistance of the line from short circuits or other causes. In exchanges using almost entirely the underground system, this arrangement might prove satisfactory, as there the danger of line disturbances is rendered very small.

13. Lamp Controlled by Relay.—A better arrangement of the line signal is to include a relay directly in the circuit of the line-wire, which relay will be operated by the change in current brought about by the change in resistance at the subscriber's station when the subscriber removes his telephone from the hook. In the local circuit of this relay is included the lamp signal and a separate battery, so that the current through the lamp will always be practically constant. A system embodying this feature is shown in Fig. 10. In this, the arrangement at the subscriber's station is the same as that shown in Fig. 9, with the exception that the condenser is omitted and the bell wound to a resistance of about 5,000 ohms. The line-wires *1* and *2* from the subscriber's station terminate in the contact points *3* and *4* of the line cut-off relay *E*. The circuit is completed by means of the levers of this relay through the battery *B* and the lamp-signal relay *C*. When the subscriber removes his receiver from the hook, the low-resistance path so formed allows enough current from the battery *B* to flow through the circuit of the line to operate the lamp-signal relay *C*. This relay, by attracting its armature, closes the circuit between the wires *5* and *6*, thus allowing current from the battery *B'* to flow through the lamp signal *L*, returning by ground. This illuminates the lamp, attracting the attention of the operator. When the operator plugs in, the tip and sleeve contacts *t* and *s* make contact, respectively, with the two springs of the jack *J*, thus connecting the cord circuit with the line in the ordinary manner. A third contact *u* on the plug makes connection with the thimble *d* of the jack, thus completing a circuit from the battery *B'* through the wire *9* and the magnet of

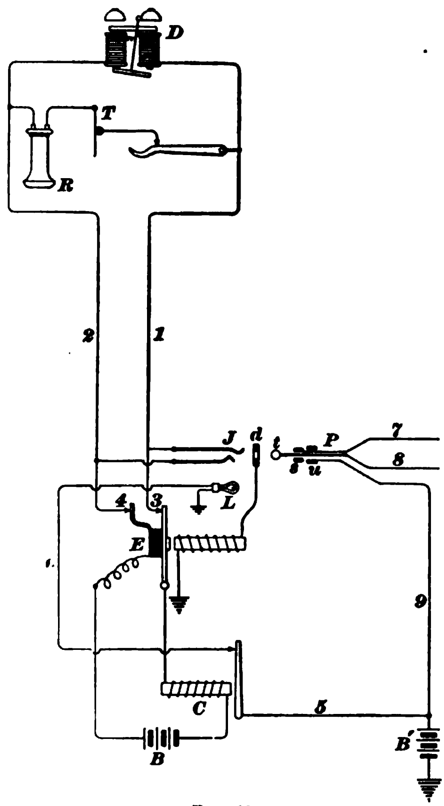


FIG. 10.

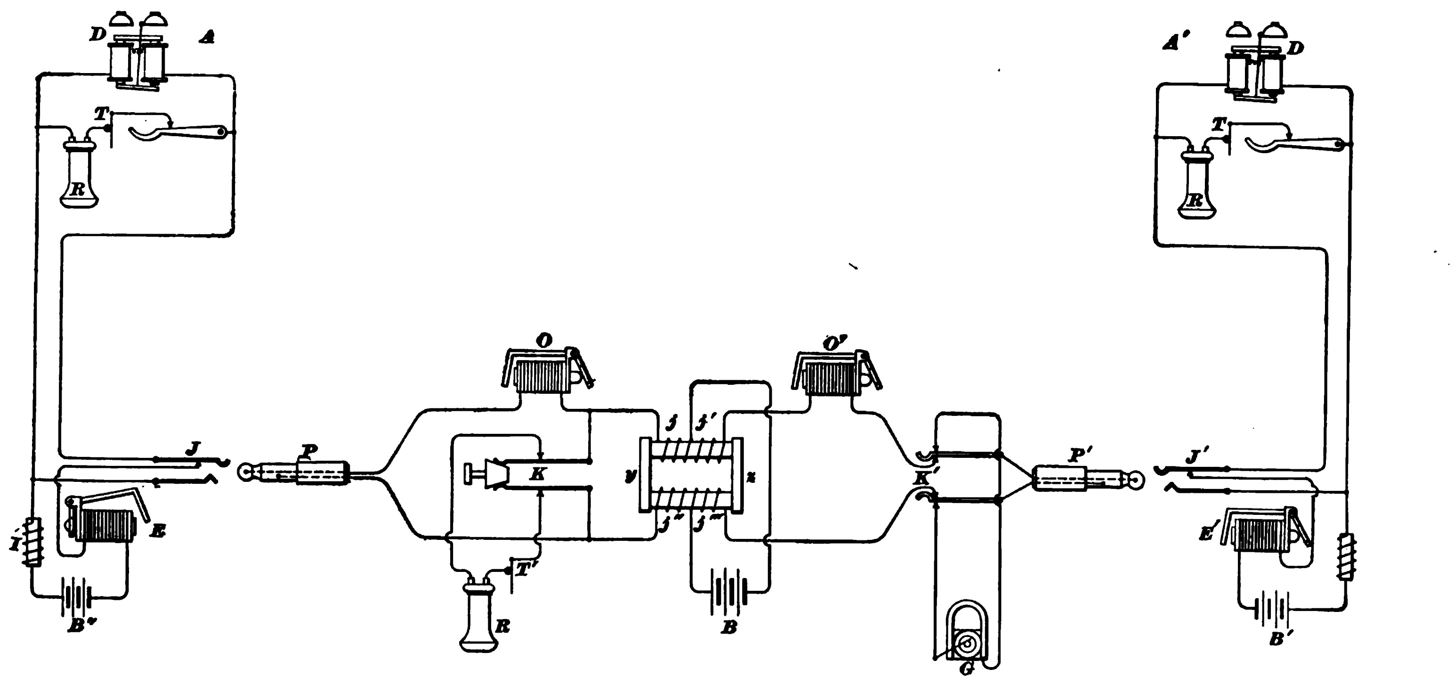


FIG. 11.

the line cut-off relay *E*, the return being made through the ground. This energizes the magnet of this relay *E*, causing it to attract its armature, thus breaking the contact at points *3* and *4* and cutting off the line beyond the spring-jack. The breaking of contact at points *3* and *4* also opens the circuit of battery *B* through the lamp-signal relay *C*, which releases its armature and opens the circuit containing the battery *B'* and the lamp *L* and causing the latter to be extinguished.

COMPLETE SYSTEM FOR SMALL EXCHANGES.

14. Arrangement of Circuits.—In Fig. 11 is shown the circuits of a modern common-battery system for exchanges of moderate size, embracing a feature not heretofore considered. This feature consists in the use of supervisory signals in the cord circuit, by the operation of which the operator is at all times made aware of the condition of any two lines connected together for conversation. The arrangement of the line circuit is the same as that shown in Fig. 9, with the exception that an electromagnetic signal *E* is used in the place of the lamp. These signals are so arranged that the target is lifted and thus displays the line number when the magnet coil is traversed by a current, the target automatically dropping back into its normal position when the current ceases. The cord circuit is arranged according to the Hayes system for supplying transmitter current to the subscribers' stations, the coils *j* and *j'* being wound on one iron core and *j''* and *j'''* on the other, the magnetic circuit of the core being completed through the two iron yoke pieces *y* and *z*. This makes the impedance to alternating currents much higher than it would be if the iron circuit was not completely closed, as would be the case were the connecting yokes *y* and *z* omitted. The terminals of the coils *j* and *j'* are connected together and to the negative pole of the battery *B*, the remaining terminals being connected with the tip strands of the cord circuit. In a similar manner, the coils *j''* and *j'''* are connected together and to the positive pole of the battery B, the remaining terminals being connected with the sleeve strands of the cord circuit. This arrangement will be seen to be the same as that shown in Fig. 6, and its operation is the same. Connected in the tip strand of each cord are the electromagnetic signals O and O', adapted to be operated by the passage through the subscribers' talking circuits of the current from battery B. By a key K the operator's circuit, including the transmitter T' and the receiver R, may be bridged across the circuit, and by a similar key K' the generator G may be connected with the calling plug P'.

15. Operation.—To understand the operation of the signals, assume that subscriber A desires a connection with subscriber A'. Upon the removing of his receiver from its hook, the signal E is automatically displayed by the passage of the current from battery B'' through the circuit. The operator answers with the plug P, thus opening the circuit through the signal E, which is restored by gravity. Current from the battery B now flows through the line and cord circuit, thus causing the magnet of signal O to raise its target. Having ascertained the subscriber desired, the operator inserts plug P' into the jack of the line leading to subscriber A', and operates the ringing key K'. The insertion of the plug P' will not cause the signal O' to operate, because of the high resistance of the bell D at that station. As soon, however, as the subscriber A' lifts his receiver, a low-resistance path will be formed between the two sides of the line circuit, through the receiver and transmitter, thus allowing a comparatively large current to flow from the battery B, which will cause the target of signal O' to rise. This will inform the operator that subscriber A' has responded. If the signal O' is not raised, she will know that the subscriber has not responded and will ring him up again.

16. Supervisory Signals.—The two subscribers converse as already described in connection with Fig. 6, the coils j and j'' acting as primaries and j' and j''' as secondaries when subscriber *A* is talking. When subscriber *A'* is talking, the functions of the coils are reversed. Both supervisory signals *O* and *O'*, Fig. 11, remain up as long as the subscribers remain in conversation. When, however, either one of them hangs up his receiver, the low-resistance path through his instrument will be broken and replaced by one of high resistance, and the signal *O* or *O'* will fall, owing to the reduction in current through it. When both signals are down, the operator knows that the conversation is finished. If only one falls, the other remaining up, the operator concludes that one of the subscribers desires another connection, and inquires of him what it is.

The signals *O* and *O'* are often replaced by lamp signals, which, however, are not included directly in the cord circuit, but in separate circuits controlled by relays placed directly in the cord circuit, in positions corresponding to the magnets of signals *O* and *O'*. This arrangement will be fully described in connection with the multiple-board common-battery system.

MULTIPLE-BOARD COMMON-BATTERY SYSTEM.

17. Arrangement of Circuits. — Fig. 12 shows in detail the circuits of a common-battery system as applied to a modern multiple switchboard of the most approved type. *A* and *A'* are subscribers' stations, each provided with a polarized bell wound to a very high resistance in a permanently closed branch between the two sides *1* and *2* of their respective metallic-circuit lines. In a normally open circuit is placed a telephone receiver and a transmitter connected in series. This branch is closed by the switch hook when released from the weight of the receiver. The line-wires pass through the various sections of the multiple switchboard, being connected with a spring-jack *J J'*, etc., at each section. Beyond the last spring-jack connected with the circuit, the two sides of the line pass through the contacts *3* and *4* of the relay *E*, commonly termed the line cut-off relay. After passing through these contacts, one side of

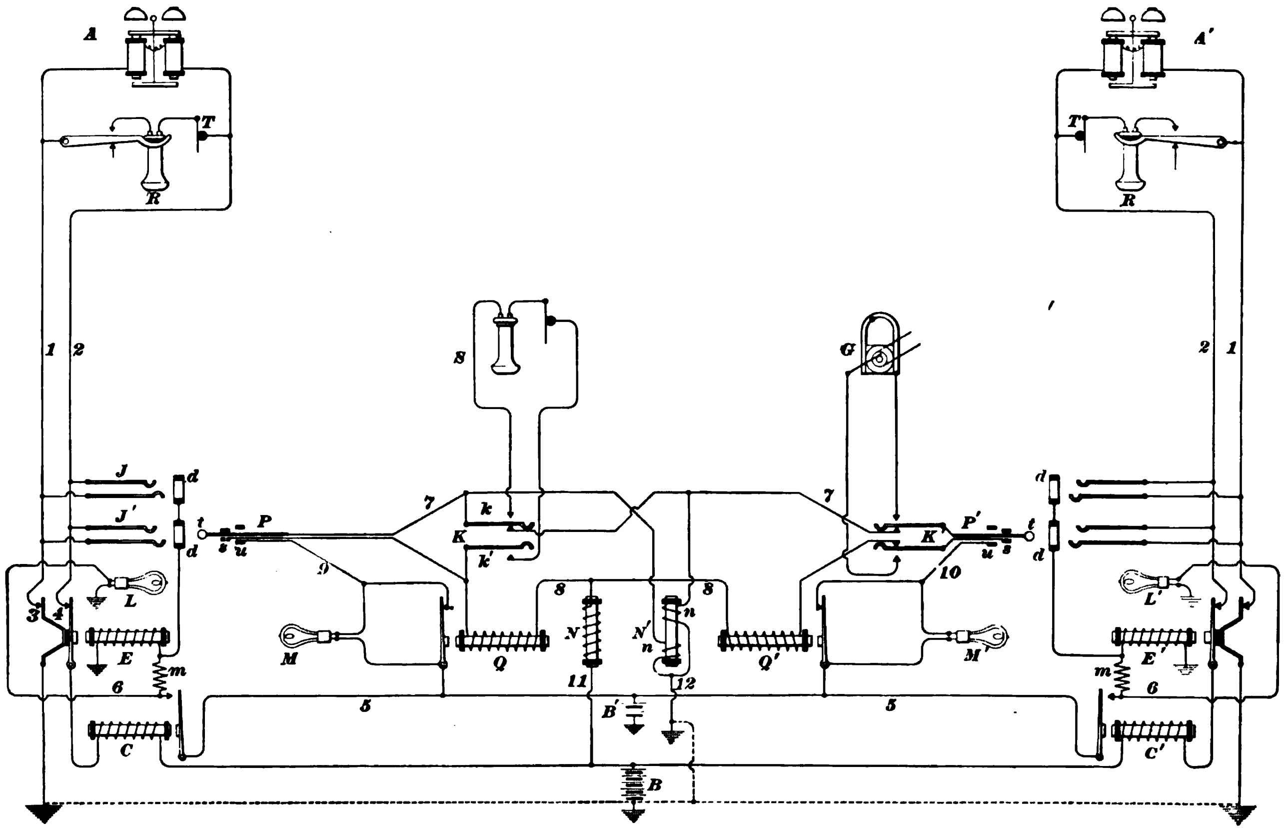


FIG. 12.

the line-wire is grounded directly, while the other passes through the winding of the relay *C* and the battery *B* to ground. The relay *C* is termed the "lamp-signal" relay, and its armature controls the continuity of a circuit containing the battery *B'* and the lamp signal *L* belonging to that line. This circuit may be traced, when the lamp-signal relay *C* is closed, from ground, through battery *B'*, wire *5*, wire *6*, and lamp *L* to ground. The winding of the line cut-off relay *E* is included in a wire extending from the ground to all the test thimbles *d* belonging to that line. The plugs *P* and *P'* have their tip contacts *t* connected by a wire *7* forming the tip conductor of the cord circuit, while the sleeve contacts *s* are similarly connected by a wire *8* forming the sleeve conductor of the cord circuit. The contacts *t* and *s* register, respectively, with the short and long springs of the jack into which the plug is inserted, thus connecting the cord circuit with the sides *1* and *2* of the line circuit. A third contact *u* is provided on each plug, and is adapted to make contact with the test thimble *d* when the plug is inserted into a jack. The thimble *u* on the answering plug *P* is connected by a wire *9* through a lamp signal *M* to one terminal of the battery *B'*, and the contact *u* on the calling plug *P'* is similarly connected by a wire *10* through the lamp *M'* to the same pole of the battery. Around the lamps *M* and *M'*, which are termed supervisory-lamp signals, a shunt circuit may be closed, this circuit in each case being controlled by the armature of a relay *Q* or *Q'* connected serially in the sleeve strand of the cord circuit. A permanently closed bridge, between the tip strand *7* and the sleeve strand *8* of the cord circuit, is formed by the conductors *11* and *12*, which include the battery *B*, together with the windings of two impedance coils *N* and *N'*. The winding *N* is located in the wire *11*, between the battery and the sleeve conductor, and the two windings *n* and *n* of the the other coil *N'* are interposed between the other pole of the battery and the tip conductor *7* of the plug circuit. The two coils *n* and *n* are normally connected in multiple, their upper terminals being short-circuited by the spring *k* of the listening key *K*. When this key is depressed, the operator's telephone set *S* is bridged across the cord circuit. It will be noticed that the bridged circuit formed by wires *11* and *12* is very much the same as that of the Stone system, shown in Fig. 4, it containing a common talking battery *B* and the impedance coils *N* and *N'*.

18. Signaling the Operator.—The functions of the various parts of the apparatus may best be understood by a description of the operation of the system, assuming that subscriber *A* desires a connection with subscriber *A'*, and tracing the various steps necessary to connect and finally to disconnect them. When subscriber *A* removes his receiver *R* from its hook, a low-resistance path is closed between the line-wires *1* and *2*, this path being through the receiver and transmitter in series. The reduction in resistance between the two sides of the line allows enough current to flow from the battery *B* through the winding of the lamp-signal relay *C* to cause that relay to attract its armature. This circuit may be traced from the positive pole of the battery *B* through the winding of the relay *C*, contact point *4*, line-wire *2*, transmitter and receiver at the subscriber's station, line-wire *1*, contact *3* to ground, and to the negative pole of the battery *B*. As stated, this current causes the relay *C* to attract its armature, thus closing the circuit from the battery *B'* through wires *5* and *6* to the lamp signal *L*, the return being made through the ground. The lamp *L* is thus illuminated and attracts the attention of the operator whose duty it is to answer calls originating on that line.

19. Operation of Cut-Off Relay.—In response to this signal, the operator inserts one of her plugs *P* into the answering jack *J'*, thus connecting the cord circuit with the line-wires *1* and *2*. This connects the positive pole of the battery *B'*, through the supervisory-lamp signal *M* and the wire *9*, with the thimble *d* of the jack, from which the current flows through the winding of the line cut-off relay *E* to ground and back to the negative pole of this battery. This causes the relay *E* to attract its double armature, thus opening contact points *3* and *4* and cutting off both sides of the line of subscriber *A* beyond the spring-jacks, and thus isolating that line from the others. The opening of contact points *3* and *4* also breaks the circuit through the lamp-signal relay *C*, and causes it to release its armature, thus extinguishing the lamp *L*.

20. Communication With Operator. — Upon the insertion of the plug *P* into the jack, current from the battery *B* at once flows through the impedance coils *N* and *N'* to the cord conductors, and thence through the tip and sleeve springs of the jack to the subscriber's station. This current, which is for the operation of the telephone instruments proper, also serves to cause the relay *Q* in the sleeve strand to attract its armature, thus completing a short circuit about the supervisory-signal lamp *M* and preventing its illumination. It must be remembered that the relay *Q* remains energized as long as the subscriber at station *A* is using his telephone, and will thus, by maintaining the short circuit around lamp *M*, prevent its illumination. By operating the key *K*, the operator bridges her telephone set *S* across the circuit, and ascertains the wishes of the subscriber *A*. Having found that he desires connection with subscriber *A'*, she applies the tip *t* of the calling plug *P'* to the test thimble *d* of that subscriber's jack, in order to ascertain whether or not his line is in use.

21. Calling the Called-for Subscriber.—Assuming that she finds the line free, she inserts the plug *P'* into the jack of the subscriber called for, and by depressing key *K'* connects the calling generator *G* with the line of subscriber *A'*. The insertion of the plug *P'* completes a circuit from the battery *B'* through the lamp *M'*, wire *10*, contact *u*, test thimble *d*, and cut-off relay *E'* to ground. This operates the relay *E'*, and at the same time illuminates the supervisory lamp *M'*, the short circuit around this lamp not being closed, by virtue of the fact that the resistance of the subscriber's circuit is so high as to allow an insufficient current from the battery B' to flow through the relay Q'. The illumination of this lamp M' informs the operator that the subscriber A' has not yet responded. As soon as he removes his receiver from its hook, a low-resistance path is closed between the line-wires at his station, thus allowing a considerable current to flow from the battery B through the cord circuit and his line circuit, thus causing the relay Q' to attract its armature to complete the short circuit around the supervisory-signal lamp M'. The extinguishing of the lamp M' informs the operator that the subscriber A' has responded. The two subscribers may now converse, current being supplied to their transmitters from the battery B in the same manner as in the circuit shown in Fig. 4.

22. Test for Busy Lines.—We have stated that the operator applied the tip t of the plug P' to the test thimble d of the jack in order to determine whether the line of subscriber A' was in use or not. The test depends upon the connection of all the test thimbles d of a busy line with the positive pole of battery B', and this connection may be brought about in two ways: either by the operation of the relay C, caused by the subscriber's removing his receiver from its hook, which would connect the wire *5* with the test wire leading to the thimbles d through the resistance coil m, which is wound to a resistance of about 100 ohms, or by the insertion of a plug into a jack, thus connecting the wire *5* with the test thimbles through the lamp M' and wire *10*. When either the relay C is operated or a plug inserted into a jack of a line, the test thimbles d will therefore be raised to a certain potential above the ground; and when an operator tests that line, a current will be caused to flow through the tip t of her plug, tip strand *7* of the cord, upper coil n, and wire *12*, to ground. This flow of current through the upper coil n induces a current in the lower coil n, which induced current will flow through the operator's receiver and produce the desired click. It will be noticed that by this arrangement a line will test busy as soon as the subscriber removes his receiver from its hook in order to obtain a connection with another subscriber; for as soon as he does so, the relay *C* operates to connect the positive pole of the battery *B'* with the test thimbles. In the series and branch-terminal multiple systems already described, the line tests free until a plug is inserted into one of its jacks. An operator might, therefore, test a line on which a subscriber was waiting before he had received an answer from central, and finding the line free might connect him with another subscriber who had called for him.

23. Operation of Supervisory Signals.—As long as the subscribers remain in conversation, the supervisory-lamp signals *M* and *M'* remain extinguished, because they are short-circuited by the armatures of the relays *Q* and *Q'*. As soon, however, as either subscriber hangs up his receiver, the current flowing through the line circuit from the battery *B* is cut off, or is greatly reduced, by virtue of the high-resistance bell. This allows the armature of the relay *Q* or *Q'* to drop back, thus breaking the shunt about the supervisory lamp and causing it to be illuminated by current from the battery *B*. When both of the lamps are so illuminated, the operator is assured that the connection is no longer desired, and she removes the plugs from the jacks, thus restoring all the signals and relays automatically to their normal positions.

AUXILIARY-EXCHANGE APPARATUS.

THE WIRING OF EXCHANGES.

24. Importance of Systematic Wiring.—It is a matter of great importance that all the wiring of switchboards shall be systematically and neatly done. In large exchanges especially is this necessary, for unless the multitude of wires are systematically arranged, the confusion will be so great as to render testing a very difficult matter, besides giving the entire work a very unsightly appearance. A still more important reason, which renders the systematic arrangement of the wires an absolute necessity, is the fact that space must be economized to the last degree. Where a group of wires lead from one portion of a switchboard frame to another, as, for instance, from the jack terminals to the drop terminals, it is customary to bunch the wires into cables, the cables being specially formed with a view to adapting them to the particular conditions in which they are to be used. These cables are usually composed of No. 22 tinned wire, which may have a covering such as the ordinary annunciator wire, although it is far better to use a covering composed of two wraps of silk outside of which is a single wrapping of cotton. The wire is tinned in order that it may readily take solder, and as it may be necessary to solder it at any portion throughout its length, the expense of tinning the whole surface of the wire before it is insulated is a small matter in comparison with the increased ease of working with it secured thereby. The Bell companies are now using a tinned copper wire insulated with two wraps of wool, and outside of that a braiding of wool. Wool will not burn, at least not with a flame, and for this reason the wire is called flame-proof.

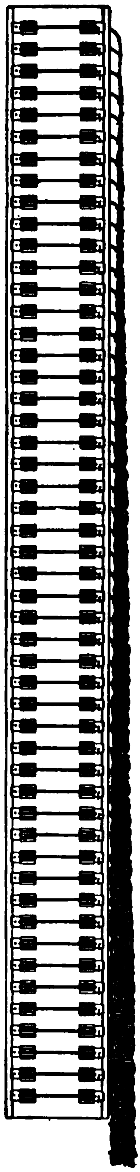


FIG. 13.

FORMING CABLES.

25. The matter of properly forming a cable is one which requires some skill and often ingenuity; and the performance of the work may be greatly facilitated by carefully planning it beforehand. One of the simplest cables to form is shown in Fig. 13, where it leads from a lightning-arrester strip having all its terminals arranged in a single row.

In order to render the description clearer, a transverse section of this strip, showing in elevation the terminals and fuse, is given in Fig. 14, while in Fig. 15 a side elevation of a portion of Fig. 13 is given, showing an end view of one of the clips. In these, *A*, *A* are a pair of clips arranged on opposite sides of the terminal strip, adapted to hold a mica fuse strip *B*, which carries a fuse *b* secured to it with shellac. The connection between the two clips *A*, *A* is thus made

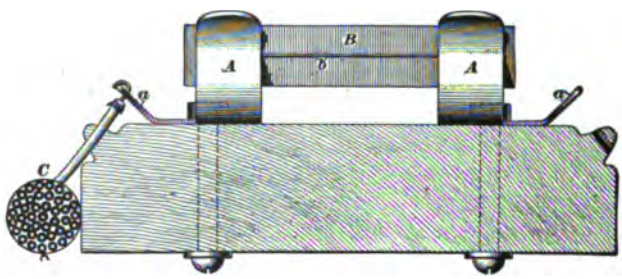


FIG. 14.

complete through the fine fuse wire *b*, when the latter is intact. A lug *a* is formed from the same piece of sheet metal as *A*, and bent up at an angle of about 45 degrees to the plane of the terminal strip, in order to form a convenient means for connecting the wires of the cable. A section of the cable is shown at *C*, one of the wires being led therefrom through a hole in the wooden strip to the lug *a*, to which it is secured by a drop of solder. The strip shown in Fig. 13 has terminals on each side for 50 wires, or 25 pairs of wires, and in forming the cable, the object is to bring out the various pairs of wires at points corresponding to the positions of the terminals, so that when the cable is laid alongside of the wooden strip, each of the various wires will come opposite its proper terminal, to which it may be secured, as already stated.

FIG. 15.

26. Directions for Laying Out Cable. — The method of procedure in this case is outlined in Fig. 16. Two rows of nails, *1*, *2*, *3*, *4*, etc., are driven in a board, the distance between the adjacent nails in the same row corresponding to the distance apart of the pairs of terminals on the terminal strip to which the cable is to be attached. The distance between the rows is made about equal to the length which it is desired to have the individual wires project laterally from the cable. No. 14, 1½-inch wire brads with small heads—or, better, with no heads at all—will be found most suitable for this work. Having determined the extreme length of the cable, which we will say is 6 feet, a wooden pin or heavy screw *P* is driven in the board at a little greater distance than 6 feet from the nails at the outer end of the row. The spool containing the twisted pair of wires is mounted in some convenient place upon a spindle so as to easily revolve. The end *a* of the twisted pair is then attached to the pin *P*, and the wire is led from that point around nails *1*, *2*, *3*, and *4* and back to the pin *P*, being kept under moderate tension all the time. It is then passed around the pin and led back to nail *5*, after which it is bent around nails *6*, *7*, and *8* and again back to the pin *P*. This process is repeated until all the nails have been engaged, the wire being continuous throughout its length. If a break should be found in the wire, it should not be spliced, but a new beginning made at the pin *P*, as at that point all wires will eventually be cut. As the cable is to have 25 pairs, there will be 25 nails in each of the rows shown, each nail serving to bring out a single pair from the cable.

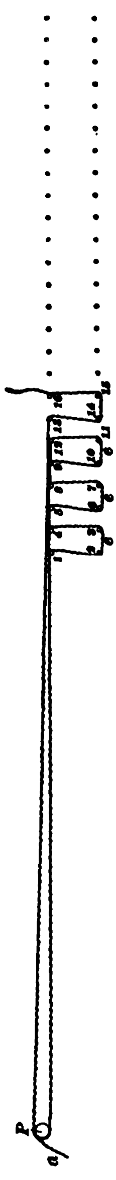


FIG. 16.

27. Lacing or Sewing.—After the wire is properly laid, it should be laced or sewed into the form of a cable before removing it from the nails. To do this a stout linen thread, similar to that used by shoemakers, but heavier, is used. The thread should be thoroughly waxed before using. A brand of thread known as Barbour's Sinew Thread is much used for this purpose, it having the advantages of being very strong and needing no additional waxing. Beginning at the end near the pin *P*, the thread is passed once around the cable and tied by the ordinary square knot, as shown at *b* in Fig. 17. The thread is then led in the direction of the wires for a distance of about $\frac{3}{4}$ of an inch, where it is again passed under the cable, then over and under itself, after which it is pulled up tight, forming what is known as the lock-stitch, shown at *c*. The method of passing the thread in forming the stitch is illustrated at *d*.

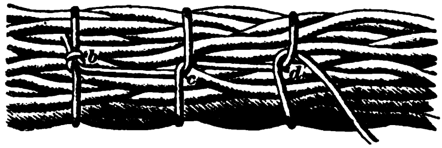


FIG. 17.

28. Wrong Method of Lacing.—In Fig. 18 is shown the wrong method of making this stitch, which a beginner is very apt to use unless specially cautioned against it. It has the disadvantage that the part of the thread which lies parallel to the cable does not lie close to the wires, as in the method shown in Fig. 17, and also that a considerable length of thread will unravel if it becomes broken at any point.

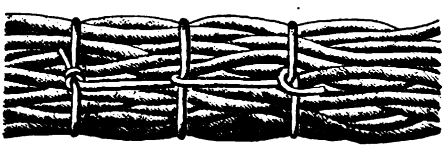


FIG. 18.

29. Cutting Loose.—The stitch should be repeated at regular intervals throughout the length of the cable. When the first nail *1* is reached, the stitch should be taken just at the point where the wire is led around it, as shown in Fig. 19, so as to include that wire under the stitch. The next stitch should be taken just at the second nail, where the second pair is led off, and so on, the process being repeated at every nail in the row nearest to the cable. After the cable is laced, all the wires should be cut at the pin *P* and also at each of the points marked *e* in Figs. 16 and 19. This renders the cable complete, it being readily seen that there are now 25 distinct pairs of wires running through it, the pairs

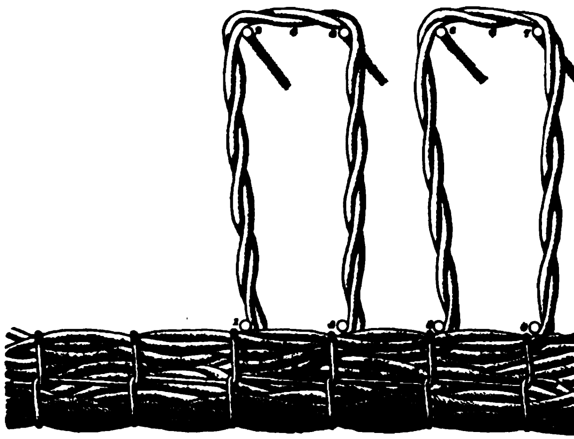


FIG. 19.

being brought out from the cable at intervals corresponding to the terminals on the terminal strip. The end at the pin *P* was not formed in this case, but it usually happens that both ends of the cable can be formed at once where needed, in the same manner as in the right-hand end of Fig. 16. The proper spacing of the nails is, of course, a matter which must be determined in each case by the existing conditions.

30. Bends in Cables.—In case the cable must, when in place, have one or more sharp bends in it, it is far better to form the cable with the bends at the proper places, as in this way a clean square turn can be made, which could not be done by bending a large straight cable after forming. Any number of sharp bends may be made in a cable while it is being formed, by carrying the wires around pins placed in the forming board at proper points.

31. Soldering to Terminals.—After the cable has been cut loose from the forming board, the ends of the various wires should be "skinned" for a distance of about half an inch, in order to permit of soldering to the terminals. The terminals are usually provided with a small hole in their ends through which the wires should be run before soldering. It is found best, in connecting up a cable having a large number of terminals, to place all the wire ends in their proper positions before soldering. The wire should in each case be bent back upon itself after passing through the hole in the terminal, in order to secure it in place. After all the wires are in position, they may be very rapidly soldered by the use of a soldering iron. As before stated, no acid should be used in this process, on account of its liability to corrode the terminals. This is of especial importance in switchboard work.

32. Fastenings for Cables.—It is usually necessary to secure the cable in position against the framework of the switchboard or other structure, and the best way to do this is by the use of short rawhide straps, the ends of which are held against the woodwork by round-head wood-screws passing through small copper washers, as shown in Fig. 20. A very neat appearance may be given to the work by giving the cable a coat of good shellac after it is in place and all the connections made. It is sometimes more desirable to do this before the cable is put in place in the switchboard. This coating of shellac, besides improving the appearance, renders the adhering of dust to the cable less liable to

FIG. 20.

happen, and at the same time stiffens the cable, thus making it hold its form better.

33. Ready-Made Cables.—Where long cables are necessary in switchboard work, as, for instance, from the switchboard terminals to the distributing terminals, it is a very tedious matter to form up a cable by the methods described, and better results can be obtained by using cable already manufactured. This may be procured in various forms and according to almost any specifications required. Cables of this kind are usually covered with several wrappings or braidings of cotton or linen, the outside one often being impregnated with a fire-proof or slow-burning paint. It is desirable that the inner covering of the cable shall be a wrapping instead of a braiding, as in "skinning" the cable, the outer braiding may be cut with a sharp knife without approaching too near the conductors themselves. The inner covering, if it is a wrapping, may be readily removed by unwinding, while if it is a braiding it must also be cut, and it is difficult to do this without injuring the wires. Cables of this kind are treated in practically the same manner as cables that are formed by hand. The ends, after having been skinned, may be shaped around pegs or nails in order to make them conform to any desired set of terminals.

34. Identifying Wires.—In ready-made cables, no means are ordinarily provided for identifying the wires at the ends. In this case the only recourse is to test them out with a magneto-bell, or receiver and battery, which in the case of rather large cables is a very tedious operation, especially where a great number of cables are used. To obviate this difficulty, what are known as circus cables have been devised and are largely used, especially in multiple-switchboard work. In these the different pairs of wires are each provided with a covering of some distinguishing color, so that the two ends of the same wire may be at once picked out by sight without recourse to testing.

PROTECTIVE DEVICES.

STATIC ARRESTERS.

35. In order to protect telephone lines and apparatus from the damaging effects of heavy currents, which are sometimes caused to flow over a line by lightning, or by reason of its being crossed with some electric light or power wire, what are termed lightning-arresters are used. The simplest form of arrester, and one whose efficiency is very much to be doubted, is that placed on every telephone at the point where the line-wires enter the instrument. This consists merely of three flat metal plates, each with a binding-post attached, as shown in Fig. 21. These plates are usually mounted on the top of the magneto-box and in such position that they are entirely insulated from each other, although almost in contact. The adjacent surfaces are made in saw-tooth form for the purpose of facilitating the passage of the spark across the gap. For this reason, this form is called a saw-tooth lightning-arrester. The two outside binding-posts, secured to the plates *A* and *B*, are connected, respectively, with the two sides of the line-wire, while the center post, secured to the plate *C*, is connected with the ground. In case the circuit on which the telephone is used is grounded instead of being a metallic circuit, the line-wire is attached to one of the outside binding-posts, the other two being connected together and grounded.

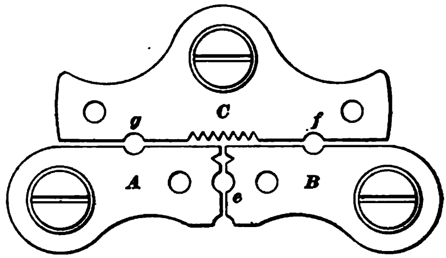


FIG. 21.

By inserting a metal plug, furnished with the arrester, in any one of the holes *g*, *f*, or *e*, any two of the plates may be connected together. This is often very convenient for testing purposes. The theory upon which this arrester is supposed to operate is that the high-tension current, such as would be produced by a stroke of lightning, will jump across the small air-gap and pass to the ground rather than pass through the various coils on the inside of the box.

The resistance offered by the air-gap between the plates *A* or *B* and plate *C* is the same for currents of high or low frequency as it is for steady direct currents; for the coefficient of self-induction of a simple air-gap is zero, and therefore the expression $\sqrt{R^2 + (2 \pi n L)^2}$, for the impedance of the gap, reduces to *R*, that is, to its simple ohmic resistance. But the impedance of the coils in the telephone set to lightning discharges, which have besides a high potential a very high frequency, is very much larger, on account of their relatively high coefficient of self-induction, than the resistance of the air-gap, and therefore the lightning discharge jumps across the air-gap because it is the easier path of the two to the earth. Direct or low-frequency currents will not jump the air-gaps between any of the plates, where the difference of potential is very great, because to them the coils and return-line wire offer an easier path. Furthermore, the electromotive forces of lighting and power circuits ordinarily in use, and against which the telephone-wire may come into contact, are not high enough to start an arc between the plates.

These arresters undoubtedly do some good in case the lightning strikes, although it is not infrequent that the current will jump across the gap and go into the box besides. For protection against comparatively low-tension currents, however, these arresters are useless, as the almost infinite resistance of the air-gap proves an effectual barrier to the starting of the current.

FUSIBLE ARRESTERS.

36. A form of arrester largely used among the independent telephone companies consists of a small fuse block, upon which is mounted a very fine fuse about two inches in length. In order to prevent breakage of the fuse wire itself, it is usually mounted on a thin strip of mica, being secured thereto by shellac. The mica strip is provided with tin-foil terminals, which may be slid between the clips of the fuse block. The fuses used are generally rated at $\frac{1}{8}$, $\frac{1}{4}$, or $\frac{1}{2}$ ampere. These ratings are not at all reliable, however, and it is not an unusual thing to find a fuse whose rated capacity is $\frac{1}{8}$ ampere carry over 1 ampere. These fuses have the advantage that they will in many cases protect a switchboard or telephone coil from the damaging effects of low-tension currents, such as might be produced by a cross upon a line. They, however, frequently let lightning currents pass, and can not alone be depended upon to afford protection.

COMBINED STATIC AND FUSIBLE ARRESTERS.

37. In Fig. 22 is shown an arrester designed to give protection from both low and high tension currents. The

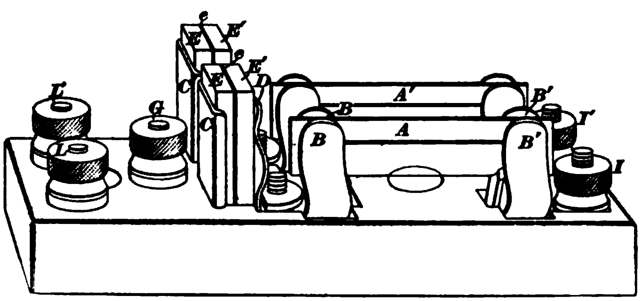


FIG. 22.

mica strips carrying the fuses are shown at A, A', being held in place between the metallic clips B, B'. C, C' are upright strips of brass permanently connected with the binding-post G, which is grounded. Between the clip C and the upright spring D, which latter is in metallic connection with the fuse clips B and also with the binding-post L, are placed two carbon blocks E and E', held apart by a thin strip of mica e. This strip of mica often has a small piece cut out at its center, as shown in e, Fig. 23, in order to allow the arc between the two carbons to start a little easier, and to permanently ground the carbon E' by fusing it to the grounded carbon *E*. *L*, *L'* are the line binding-posts, while *I*, *I'* are the posts connected with the instrument to be protected. The normal circuit through this arrester is from the post *L* to the left-hand clips *B*, then through the fuse wire to the right-hand clips *B'* and to the binding-post *I*. A current of sufficient strength will melt the fuse on *A* and open the circuit. If the current is of sufficiently high voltage, it will jump across the small gap between the two carbon blocks *E*, *E'* formed by the mica strip *e* and pass to the plate *C*, and thence through the binding-post *G* to ground.

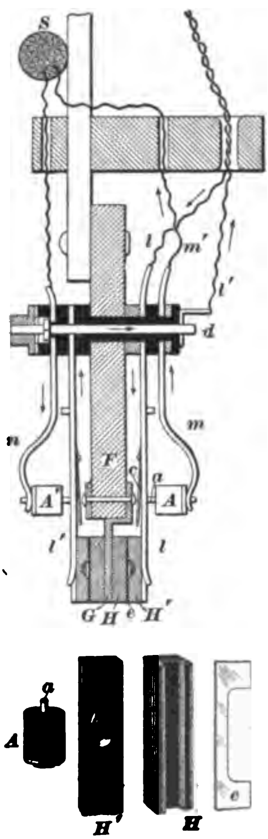


FIG. 23.

HEAT-COIL ARRESTER.

38. Heat Coils.—A much better form of arrester is that known as the heat-coil, or sneak-current arrester, one form of which is shown in Fig. 23, in combination with a static arrester in the form of carbon blocks. In this figure, the protecting device is shown attached to the frame of the main distributing board. The small hollow cylinders *A*, *A'* contain what are called the heat coils, a detached view of one of which is shown in the lower portion of the figure. This consists of a coil of fine, silk-covered, German-silver wire, made of 34.5 inches of No. 37 B. & S. gauge, wrapped about a small metal plug *a*, which is held in its place by a drop of solder of such composition that it will fuse at a very low temperature. The passage of a very small amount of current, about .3 of an ampere for 30 seconds, through the coil will cause the solder to melt, and thus release the pin *a*. The resistance of this coil is about 28 ohms. The heat coil is protected by the hollow cylinder *A* of fiber or hard rubber. The heat coils are normally held between two springs *m* and *l* and *n* and *l'*, as shown. The pin *a* projects through a slot in the spring *l* and rests against a small flexible spring *c* riveted to the spring *l*. To the spring *l* is attached the line-wire *l*, while to the spring *m* is attached the wire *m'* leading to the switchboard through the cable *S*. As the heat coil is included in the circuit between these two springs, it follows that whatever current passes over the line-wire must pass through the small German-silver coil inside of *A*. The plate *G* is grounded, and upon it rests the carbon block *H*; the other carbon block *H'* of the pair rests under the spring *l*, and, as in the preceding figure, the two blocks are held apart by a thin strip of mica *e*.

39. Improved Static Arrester.—An additional precaution is provided by enclosing in a slight depression in one of the blocks a drop *h* of fusible metal so arranged that it will not touch the other block of the pair when the mica strip is between them. The operation of this device is as follows: If a current caused by a high potential, 300 volts or over, comes in over the line *l*, it will pass by spring *l* to the carbon block *H'*, and will jump across the air-gap to the block *H* and to ground. If the discharge is of sufficient duration, the fusible alloy in block *H'* will be melted, thus completely grounding the line. If a low-tension current, commonly termed a sneak current, comes in over the line, it will pass from the spring *l* through the heat coil to the spring *m* and through the switchboard drop. After a very short interval of time, the heat developed in the coil will melt the solder, thus releasing the pin and allowing the spring *m* to force the pin *a* through the coil, and this pin presses the small spring *c* into engagement with the ground plate *G*. This throws a dead ground on the line, and at the same time the spring *m* makes contact with the spring *l*, thus short-circuiting the switchboard apparatus.

The arrester mounted on the other side of the strip *F* forms the protection for the other side of the same line circuit. The line-wire *l'* is connected with the spring *l'* through the bolt *d* passing through the strip. This bolt makes connection only with the lower spring *l'*, which is the mate to the spring *l* on the other side of the strip. The heat coil *A'* is connected in an exactly similar manner between the springs *l'* and *n*. The operation of the arrester on this side of the strip *F* is precisely the same as that on the other side. The arrows show the path of the telephone current under normal conditions.

40. Danger of Sneak Currents.—The peculiar danger in sneak currents is that they do not make themselves evident to the senses at once, the first indication of their presence being the smoldering of a coil in the switchboard or telephone caused by the long-continued flowing of the current. There are very few coils used in telephone work which will not stand $\frac{1}{8}$ of an ampere for a short time, but the flow of such a current for a long time might generate enough heat to char the insulation and spoil the coil. The heat coils form the most effective prevention for currents of this character. By varying the length of the German-silver wire used in their construction, they may be made to have almost any degree of sensitiveness desired. They are often constructed so as to melt the solder when a current of $\frac{1}{8}$ ampere flows through the coil for 25 seconds.

41. Sterling Sneak-Current and Lightning Protector.—Fig. 24 illustrates the combined sneak-current and lightning protector made by the Sterling Electric Company for use upon individual telephones. It is double-pole, i. e., it protects the apparatus from dangerous currents entering over either line-wire. One line is connected to the binding-post *A*, the other to *C*. From *B* a wire goes to the telephone; the other binding-post from which the other wire goes to the telephone is not in view. The binding-post *E*, to which the piece *e* is fastened, is connected by wire with the ground.

There are two pairs of carbon blocks, one pair in each line circuit. One block of each pair is separated and insulated from the other similar block by a piece of silk ribbon or

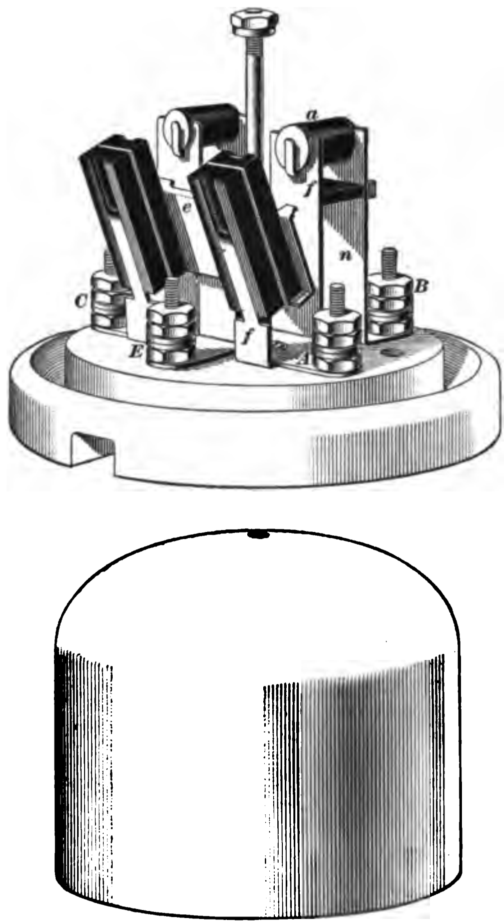


FIG. 24.

braid. Embedded in a depression in the surface of one carbon of each pair, next to the piece of silk, is a small metal or carbon ball, held in place by an easily fusible wax. A sufficiently high potential to arc between the carbons will melt the wax, and permanently ground the line, that is, the ball will fall by gravity and connect the two carbons together.

From binding-post *A* the circuit continues through the spring *f*, heating coil *a*, and spring *n* to binding-post *B*. The heating coil is shown in Fig. 25, in which *r* is a piece of hard rubber, having a tapped hole through its center.

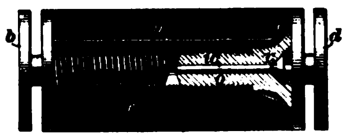


FIG. 25.

The brass pieces *b* and *o* are insulated from each other by the piece *r*, into which they are screwed. Twenty-five ohms of No. 36 German-silver wire are wound upon the piece *o* at *c*. One end of the wire is soldered to *o* and the other end to *b*, after being led through the groove *u*. The stem *w* and flange *v*, forming part of the end piece *d*, fit into corresponding hollow portions in *o*, to which they are fastened by an easily melted solder; $\frac{1}{4}$ ampere, flowing for 15 seconds, melts the solder and allows the springs *f* and *n* (Fig. 24) which engage the pieces *b* and *d* to fly apart, pulling *d* with its stem and flange entirely out of the piece *o*, thus breaking the line circuit, and *f*, coming against *e*, grounds the line. The cover (Fig. 24) is made of strong glass.

42. When this protector is located at the central exchange, a signaling device is often used to notify the attendant by the ringing of a bell when a line becomes grounded. This is shown at the left-hand side of Fig. 26, where the circuit of the local battery *B* and bell *C* is closed when the springs *n* and *m* make contact with the pins *r* and *s*, respectively. For station use, the carbons are separated by a perforated piece of mica (.005 inch thick) in place of the silk.

Fig. 26 shows the method of protecting the telephone at one end, the station apparatus at the other end, and also the line fuses for protecting the cable from excessive currents caused by crosses between the overhead telephone and electric light or power lines. One fuse is connected between the cable and the overhead line-wire and another between the overhead line-wire and the subscriber's telephone.

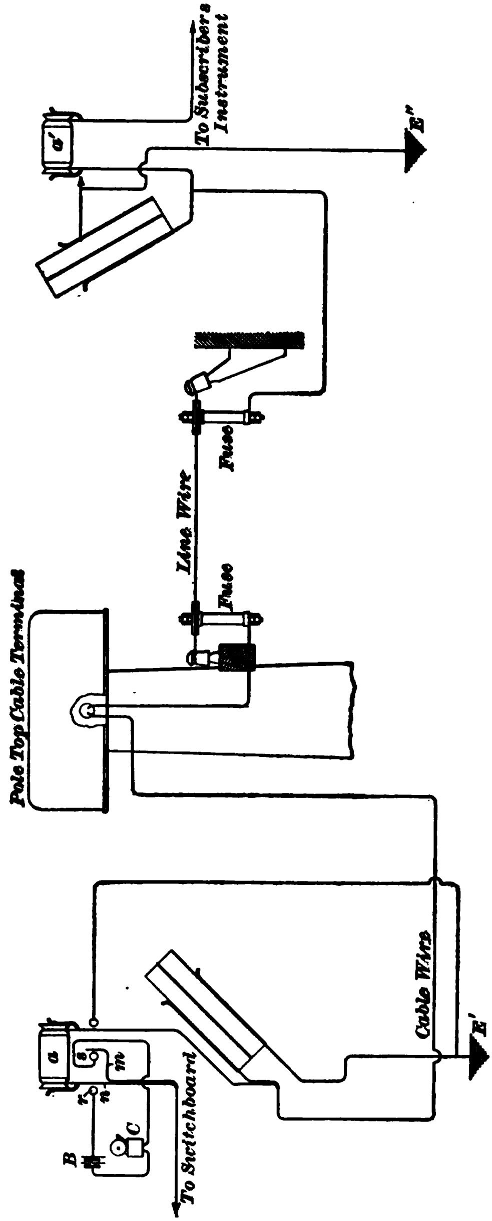

To Subscribers Instrument
a'
E''
Fuse
Line Wire
Fuse
Pole Top Cable Terminal
Cable Wire
E'
a
s
m
r
n
B
C
To Switchboard

FIG. 26.

43. Fuses.—The fuse protector, Fig. 27, consists of a hollow cylinder of enameled wood or fiber about 4 inches long and ½ inch in diameter, to the ends of which are

FIG. 27.

secured metal terminals. The fuse, the ends of which are fastened to the metal terminals, is inside the tube, which prevents the scattering of the melted metal. The tube is hermetically sealed, which protects the fuse from air-currents and makes it operate more uniformly by the current for which it was designed to melt. It is intended that 5 amperes should melt the fuse.

The Bell Company use for protecting their cable wires a fuse similar to that shown in Fig. 27. For cable terminals at a distance from the exchange, the fuse is made so as to be melted by a current of 8 amperes, and at the central exchange by a current of 3 to 5 amperes. Currents smaller than this are taken care of by the protecting devices at the central station and at the subscriber's telephone.

DISTRIBUTING BOARDS.

44. Desirability.—A very important feature in telephone exchanges, whether large or small, is the distributing board, by which various changes necessary in the arrangement of the line circuits with respect to the switchboard terminals may be made without disarranging the switchboard or line cables. Small exchanges are frequently constructed without a distributing board, but this is usually due to ignorance of the advantages to be derived from such a board rather than due to a lack of funds, for a distributing board for a small exchange may be constructed at a very small expense and with very little trouble.

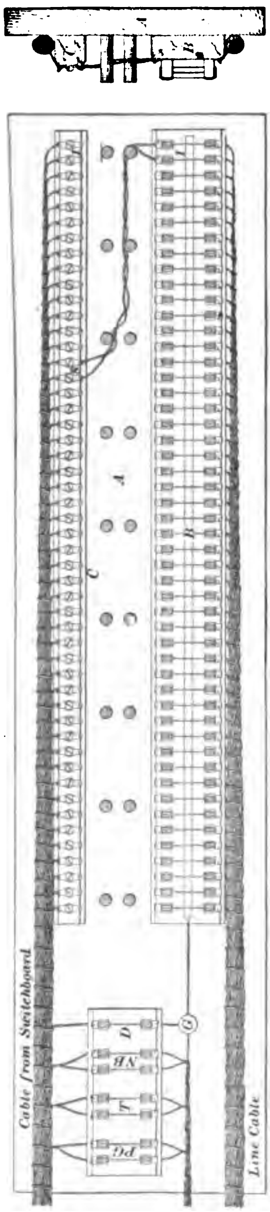


FIG. 28.

SMALL DISTRIBUTING BOARDS.

45. Design and Construction.—For an exchange having 50 subscribers or less, a very convenient distributing board may be made as shown in Fig. 28. *A* is a well-seasoned pine board 8 inches wide and long enough to accommodate as many terminals in one row as there are wires to be led to the switchboard. *B* is a lightning-arrester strip containing the requisite number of fuse clips of the general form shown in Fig. 14. It is sometimes desirable that the carbon blocks, as shown in Fig. 22, should also be present, and where this is the case, the porcelain blocks carrying the complete arresters may be mounted side by side on the board *A* instead of the extra wooden strip *B*. This strip of arresters should be mounted about an inch and a quarter from the lower edge of the board, as shown. On the same side of the board and about the same distance from the upper edge should be mounted a strip of pine *C* of the same length as the lightning-arrester strip and 1 inch square. The two edges of this should be beveled, as shown in the sectional view. Upon this strip is mounted a number of connectors corresponding to the number of terminals on one side of the board *B*. Between the strips *C* and *B* two rows of $\frac{3}{8}$-inch holes are bored in the board, these holes being placed at convenient intervals about opposite the center of every third pair of connectors. Into these holes are driven round wooden pins, long enough to project 1½ inches from the face of the board. The strip *B* is for the wires leading from the subscribers' stations, while the strip *C* carries terminals for the corresponding wires leading from the switchboard.

46. Connecting Line and Switchboard Wires.—The line-wires are formed into a cable, which is fanned out according to the method shown in Fig. 13, and the various terminals are permanently soldered to the lightning-arrester clips. In a similar manner, the wires leading from the switchboard are formed into a cable and fanned out to the terminals on the strip *C*, to which they are permanently soldered. A gap now exists between each line-wire and the wire leading to the switchboard, and this gap is bridged across by what are called jumper wires, extending from the lower terminals of the connectors on the strip *C* to the upper terminals of the arresters on the strip *B*. Inasmuch as the pair of wires terminating in clips No. *1* on the strip *B* will in all probability *not* be connected to the No. *1* pair of connectors on the strip *C*, the jumper wire will not extend straight across from the strip *B* to *C*, but will be led around the various wooden pins in a manner indicated in the figure from No. *1* on strip *B* to No. *8* on strip *C*. The jumper wire should be composed of No. 22 tinned annunciator, or, better, rubber-covered, wire in twisted pairs, and after the ends of a pair are soldered to the proper terminals on the strip *B*, the pair is led to the nearest of the wooden pins and then along the channel formed between the pins, passing around the one on the opposite side which is nearest to the pair of connectors on the strip *C* to which it is to be joined. This arrangement makes it an easy matter to change the connection of any subscriber's line from any particular switchboard drop to any other, for all that is necessary is to remove the jumper wire and carry it to the new set of terminals to which it is to be attached. In this way the opening of a cable is rendered unnecessary, no matter what changes are made in the arrangement and distribution of the wires.

47. Connections for Power and Battery Wires.—At the left-hand end of the board *A*, which is made considerably longer than the strips *B* and *C*, may be mounted a strip *D*, carrying fuse blocks similar to those used in electric-lighting work. To the terminals of these clips are led the transmitter-battery wires, power-generator wires, and, in fact, all wires which lead to or from the switchboard and which are not line-wires. These wires leading to the upper side of this strip *D* may be formed into the same cable as that carrying the line-wires to the switchboard. On the lower side, however, they are preferably made separate from the line cable, inasmuch as they lead to a separate part of the exchange. The wires to be led from an ordinary switchboard are as follows: Two power-generator wires leading from the terminals on the switchboard marked *P G* to the terminals of the power generator; two transmitter wires leading from the terminals of the local transmitter circuit on the switchboard to the terminals of the transmitter battery; two night-bell wires leading from the terminals of the night-bell circuit on the switchboard marked *N B* to the terminals of the night-bell battery; and where the switchboard requires a common-return or a grounded circuit, a single wire leading to the common-return wire or to the ground. The ground wire *G* is shown connected to a metal plate extending the whole length of *B*, so that if the carbon lightning-arresters are used, as they should be, the lower carbons, all resting on this strip, are grounded.

48. Panel Distributing Boards.—For larger exchanges many different styles of distributing board have been devised, one of the simplest of which is made by placing the strips containing the connectors for line-wires on one portion of a large flat panel, and the terminals to which the switchboard cables are connected on another portion of the same side of this panel. Holes are bored through

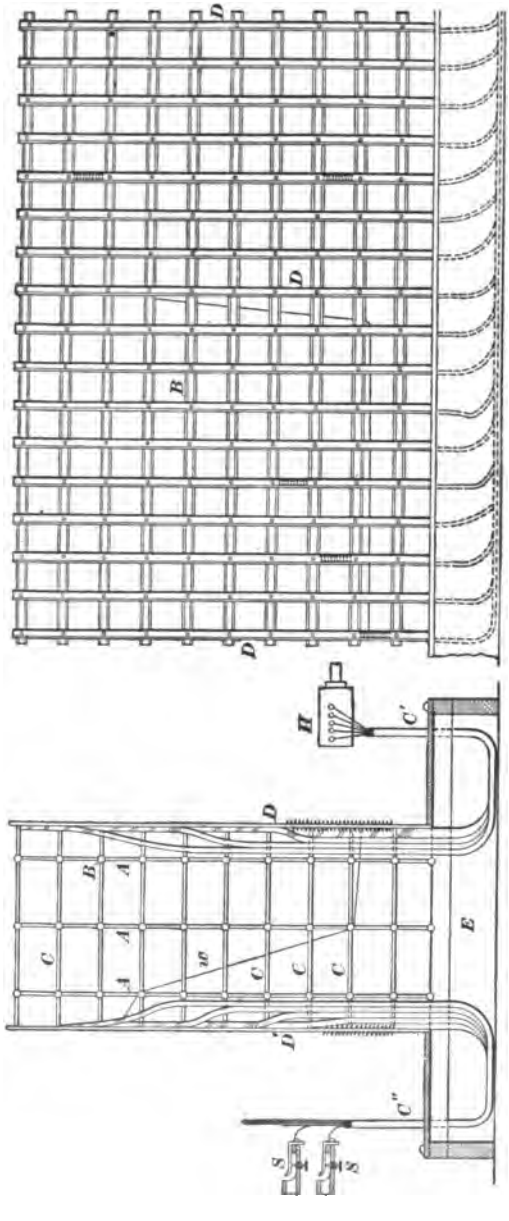


FIG. 29.

the panel opposite the various terminals, and through these holes the jumper wires pass. In making a connection from any line terminal to any switchboard terminal, the jumper wire is soldered to the line terminal, passed through the nearest hole in the panel, and thence across the back of the panel to the hole opposite the proper switchboard terminal, through which it is passed and secured as before. Wooden pins may be arranged on the back of the panel in order to confine the jumper wires to parallel paths, thus preventing a great amount of confusion. Boards of this kind may be readily constructed, and the ingenuity of the designer may be exercised to arrange the various terminals and parts to best meet the exigencies of the case in hand. Such a board as described may be made available for exchanges having several hundred subscribers, although the forms to be described later are much more desirable for large exchanges.

THE HIBBARD DISTRIBUTING BOARD.

49. Construction.—This board, designed by Mr. Angus S. Hibbard, of the Western Electric Company, has been used to a large extent in the Bell exchanges. It is built in the form of an open framework of iron pipes, the latter extending in vertical, longitudinal, and transverse directions. Upon the vertical pipes *A*, *A*, *A*, Fig. 29, are mounted the intersecting horizontal pipes *B* and *C*, the former extending longitudinally throughout the length of the board and the latter transversely. Upon the ends of the transverse pipes are mounted vertical strips *D* and *D'* of insulating material, which carry the connectors for the various wires of the line and switchboard cables. These cables are brought through a horizontal run box *E* under the distributing board and led up to and parallel with the strips *D* and *D'*, to which they are to be fanned out. The vertical portions of these cables are usually supported by being laced to the projecting ends of the transverse rods *C*, that is, to the ends between the horizontal rods *B* and the connector strips D or D'. This is clearly shown in Fig. 30, which is an enlarged plan view of a portion of the board.

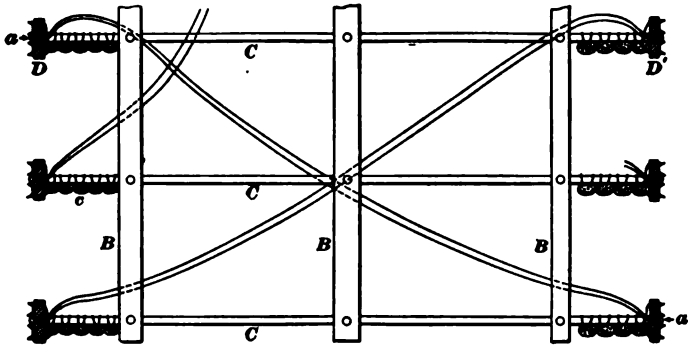


FIG. 30.

The terminal strips D and D' are arranged as shown in Fig. 31, the pairs of wires leading from the cable being led to the outside terminals of each connector, while the corresponding jumper wires w, w are led from the inner terminals of the same pair and through the hole a, as shown. This construction applies to both the switchboard and line sides of the distributing frame. The arrangement of iron pipes forms a series of horizontal runs between the vertical and horizontal pipes, and also a series of vertical channels or falls between the intersecting horizontal pipes.

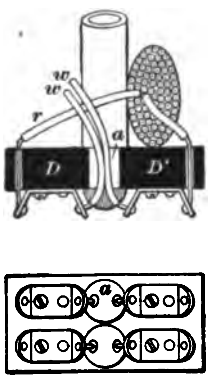


FIG. 31.

50. Path of Jumper Wires.—In leading from the line side of the distributing board to the switchboard side, a pair of jumper wires (see Fig. 29) passes through the hole a (see Fig. 30) in the strip D, and thence in a horizontal direction until it reaches the nearest vertical pipe A, around which it bends, following one of the horizontal runs until opposite the connector strip D' on the switchboard side, which carries the pair of terminals with which it is to be connected. The wire is then bent sidewise around another of the vertical pipes *A*, and then downwards or upwards over one of the longitudinal pipes *B*. It follows the vertical run until opposite the particular pair of terminals with which it is to be connected, when it is again bent around one of the transverse pipes *B* and through the hole *a* (see Fig. 30) between the proper terminals.

51. Connection of Line and Switchboard Wires.—In the end elevation shown in the left-hand portion of Fig. 29, the complete path of the line circuits from the cable heads on which the lines terminate to the switchboard jacks is shown. The cable heads are indicated at *H*, these being devices for facilitating the connection of the various wires in a line cable to other wires in the exchange. The individual wires leading from this cable head are bunched into a cable *C'* which pass into the horizontal run box under the distributing board and are led to a point directly under the terminal strip *D* on which it is to be fanned out. Here the cable is bent upwards and laced to the horizontal rods *C*, as before described, it being fanned out and connected with the outer rows of terminals on the strip. From the inner rows of terminals lead the jumper wires through the various channels in the framework to the proper terminals on the switchboard side of the frame. One pair of these jumper wires *w* is shown, and its course may be quite clearly traced. The cable leading from a section of the switchboard is indicated at *C"*, this cable being led through the horizontal run box in the same manner as the cable *C'*, and fanned out on the other side of the distributing board, the connection between the wires in the cable *C"* and those in the cable *C'* being completed, as already described, by the jumper wires *w*.

52. Arrangement of Jumper Wires.—The object of any distributing board is to render changes in the distribution of the line-wires with respect to the switchboard terminals an easy matter at all times and to prevent as much as possible any confusion arising in the jumper or bridle wires by which these changes are effected. In large exchanges, much trouble is experienced with an improperly designed distributing board, on account of the jumper wires being tangled and so crowded together as to render their subsequent withdrawal a matter of great difficulty. In such cases it is not infrequent to find the old jumper wire merely cut loose from the terminals to which it had been connected and left dead in the distributing frame. This brings about subsequent trouble, the idle or dead jumper wires adding to the general confusion without being of any service whatever. For this reason, those having the care of distributing boards should make it an absolute rule that whenever a jumper wire is cut loose at its terminals it should be pulled out, even though this entails considerable trouble. The proper arrangement of the jumper wires is a matter of great importance, and the distributing board which best accomplishes this, at the same time maintaining the wires in an open relation, is, other things being equal, the best adapted for its purpose.

THE FORD AND LENFEST BOARD.

53. In very large exchanges, as, for instance, those having multiple switchboards, another form of distributing board, designed for the most part by Messrs. Ford and Lenfest, is being largely used. This board, like the Hibbard, is constructed in the form of an open framework, but the terminals on the line side are usually arranged on horizontal strips, while those on the switchboard side are arranged vertically. The line cables are fanned out on the horizontal strips, which are arranged in tiers, one above the other, and the jumper wires pass through these strips and along horizontal shelves until they are opposite the vertical strip on which the terminals to which they are to be connected are located. The jumper wires are then passed through an iron ring opposite the terminals, and the ends soldered in place, as before. On the vertical side of the distributing board are arranged the combined lightning and sneak-current arresters, shown in Fig. 23. From the other side of these arresters are led the wires from the switchboard cable, the wires of which are fanned out and permanently soldered to the arrester terminals. The ground-plate on which these arresters are mounted is of cast iron, and all the plates on the vertical side are bonded together and connected with the ground in a substantial manner.

54. Intermediate Distributing Boards.—In the larger exchanges it is also customary to employ what is termed an intermediate distributing board, similar to the main distributing board, except that it is not provided with arresters. Where a series-multiple switchboard is used, the cables go from the vertical side of the main distributing board to the ordinary multiple jacks on the switchboard. From the last jack in each line, cables are led to the vertical side of the intermediate distributing board, cross-connected to the horizontal side, from which cables are led back to the switchboard, and are there connected to the annunciators and the corresponding answering jacks.

In switchboards where all the jacks, annunciators, or line relays are connected in parallel across the two line-wires, the cables run from the main distributing board to the vertical side of the intermediate distributing board, from which the wires branch, before crossing the latter, to the ordinary multiple jacks on the switchboard. Cables from the horizontal side of the intermediate distributing board are connected to the line relays or annunciators and the corresponding answering jacks. Then by jumpers any line relay or annunciator and its corresponding answering jack can be connected across the board to any line and its corresponding set of multiple jacks. At the main distributing board all changes in the arrangement of circuits are made that are brought about by the removal of instruments from subscribers' premises, the replacing of new instruments, or the changing of the subscriber's location.

55. The office of the intermediate distributing board is to permit of the rearrangement of lines leading to any section of the board, or, more properly, to any operator's position. Such rearrangements are often made necessary in order to equalize the amount of work performed by the various operators. It is found that some groups of lines will be particularly busy, owing to the fact that their subscribers require many connections per day, while other groups of lines will not require nearly so much attention. By means of changes performed at the intermediate distributing board, the number of lines on an exceptionally busy section of the board may be reduced by interchanging some of the annunciators and answering jacks with the sections controlled by operators who are kept less busy, and this is done without changing the subscriber's multiple jacks and his telephone number on them. It is evident that by means of jumpers at the intermediate distributing board, any line and its system of multiple jacks can be connected with any answering jack and its corresponding annunciator.

THE POWER STATION.

GENERATORS.

56. Magneto-Generators.—In very small exchanges, the calling is usually done by hand, a small magneto-generator being supplied for that purpose, which the operator turns by hand whenever she desires to transmit a signal to the line of any subscriber. For larger exchanges, the duty imposed upon the operator of turning the crank every time she desires to transmit a call becomes excessive, and in order to obviate it, constantly driven generators are employed, which may be switched into circuit by the pressure of a ringing key, or by the other methods already discussed. These power generators frequently consist of ordinary magneto-generators mounted upon a base and provided with a grooved pulley, by which it may be belted to a source of power. Such a generator is shown in Fig. 32. In this figure, the armature and pole-pieces of the generator are the same as those of the ordinary hand generator, but the permanent horseshoe magnets are somewhat larger, in order to give a stronger field. The generator shaft is prolonged and carries a grooved pulley mounted between two

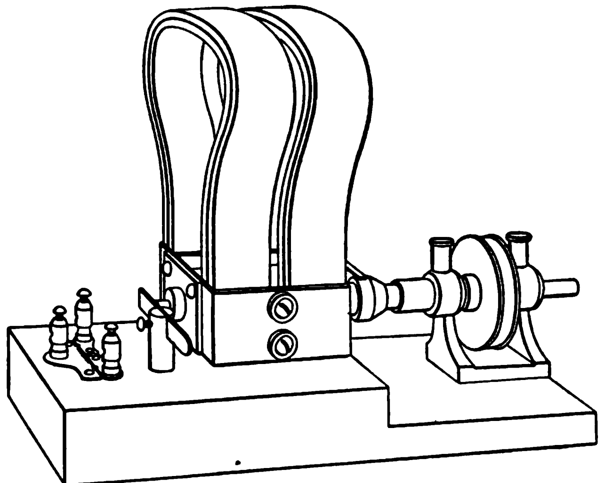


FIG. 32.

bearings, as shown. This machine is mounted upon a slate base provided with suitable terminals in the form of binding-posts, and also with an ordinary saw-tooth lightning-arrester.

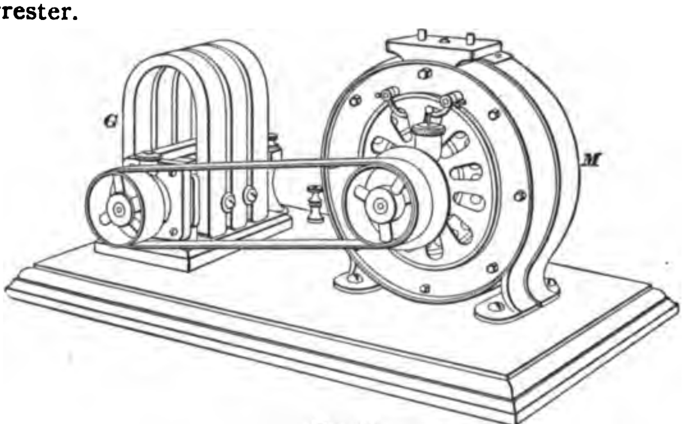


FIG. 33.

57. Electric-Motor-Driven Generator.—The means for driving generators of this general description are varied.

Where electrical power is available, the best method is to use a small electric motor, preferably mounted on the same base. These motors may be procured for any standard voltages, and for either direct or alternating current work. In Fig. 33 is shown a combination of a small direct-current motor *M*, belted to a magneto-generator *G*, mounted on the same base.

58. Motor Generators.—For operating large exchanges, by far the most desirable machine for generating

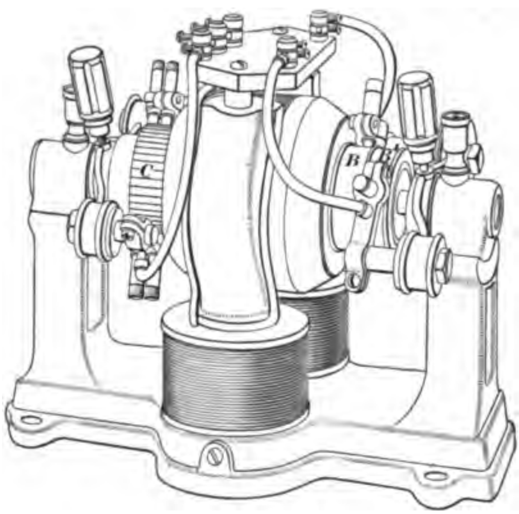


FIG. 34.

calling current is the motor generator. This is in reality a combination of a motor and a dynamo, the armature windings of the motor and of the dynamo being wound on the same armature core and revolving in the same field. Such a machine is shown in Fig. 34. At the left-hand end of the armature shaft is placed the commutator *C* of the motor windings of the armature, to the brushes of which are led the wires from the lighting or power mains, current from which is to operate the machine. On the other end of the armature shaft are mounted two separate collector rings *B*, *B'* for the generator windings of the machine, from which is taken the current for operating the call-bells. These machines are manufactured by several dynamo builders, and may be wound for any standard voltage on the motor side. The one shown in Fig. 34, however, is the product of the Holtzer-Cabot Electric Company, Boston, Massachusetts.

59. Combined Calling and Battery-Charging Generators.—Where storage-batteries are used in connection with a telephone exchange, they may be charged from the ordinary lighting mains in a manner which will be described later, but a better way is to charge them by means of current from a motor generator. Of course, direct current is needed for this purpose, and in large exchanges it is better to use a separate motor generator for this purpose, capable of giving a direct current at a voltage a little higher than that of a storage-battery. In small exchanges, however, the operation of two separate motor generators involves a needless expense, and for this purpose, machines are often constructed having two separate generator windings in addition to the motor winding. One of these generator windings is adapted to produce alternating currents at the proper voltage for actuating the polarized bells of the subscribers' stations, while the other is so wound as to produce direct current at the proper voltage for charging the storage cells; this latter winding, of course, is brought out to a continuous-current commutator.

60. Cut-Outs for Battery Chargers.—Machines for charging storage-batteries should be provided with some form of cut-out to automatically open the charging circuit should the machine stop running, otherwise the storage-battery will be short-circuited by the armature winding of the generator when the latter ceases to run. The current flowing from the storage-battery will then tend to make the machine run as a motor, thus wasting the energy of the battery, and sometimes permanently injuring the battery itself, owing to an excessive rate of discharge. These cut-outs are made in several forms, one, manufactured by the Crocker-Wheeler Electric Company, being shown in Fig. 35, as applied to a motor generator for charging storage-batteries. In this figure, C is the commutator on the motor side of the machine and C' that on the generator side. The front field core A is hinged at its base, and when the generator is not supplied with current, is held away from the armature by a spiral spring S. The top of the field core

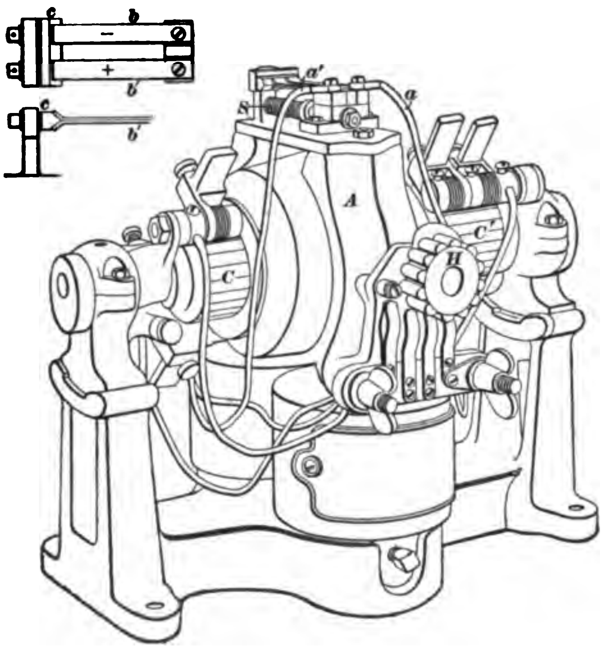


FIG. 35.

carries the switch contacts b and b', to which the leads a and a', forming a part of the storage-battery charging circuit, are connected. These springs are shown in the small detail view in Fig. 35, and are insulated from each other as long as the pole-piece A is held away from the armature by the strength of the spring S. As soon as current is supplied to the motor side of the machine, the pole-piece is drawn towards the armature by the magnetism of the field coils and armature. This connects the springs b and b'

together through the stationary contact *c*, thus completing the charging circuit, which includes the generator winding on the machine and the storage-battery. When for any reason the source of current fails, the magnetism in the field is reduced and the hinged pole-piece falls back, thus preventing a discharge of the storage-battery through the motor. *H* is the handle of a rotary switch by which the strength of the field, and therefore the speed of the machine, may be controlled.

61. Water-Motors. — Where electric power is not available, water-power is frequently resorted to where a sufficient pressure can be obtained. Water-motors of the type shown in Fig. 36 are obtainable for this purpose, and will operate satisfactorily in driving magneto-generators where a pressure of 40 pounds per square inch can be obtained in the city mains or elsewhere. In Fig. 36, *S* is the supply pipe leading to the motor, and *O* the outlet pipe for carrying away the water after its use. This latter pipe should be perfectly straight for a distance of at least 20 feet from the motor. These motors operate by a jet of water flowing through a small nozzle and impinging against buckets on a wheel within the casing. The bore of the nozzle is usually about $\frac{1}{16}$ inch in diameter on the small sizes of machine, and if sufficient power is not obtained with this size, the nozzle may be drilled out to a larger size by an ordinary twist drill.

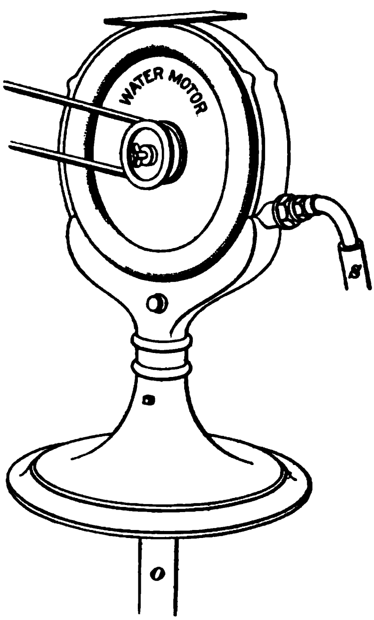


FIG. 36.

62. Another way of driving a magneto-generator is to place it in a factory or power station where there is machinery in constant operation. The motor may be belted directly to some shaft and the current from it carried to the exchange by a metallic circuit composed preferably of No. 12 B. & S. gauge, copper wire. This method is very convenient, and as the power required to run the generator is almost inappreciable, the company in whose plant it is located will usually make no objection.

STORAGE-BATTERIES.

INSTALLATION AND CARE OF BATTERIES.

63. Setting Up.—After unpacking the plates of a storage-battery, they should be carefully dusted off and all particles of packing material removed. The elements should then be placed in the jars, care being taken that the positive and negative plates do not touch each other. Insulating blocks of one form or another are always provided with cells for this purpose. The cells should then be connected with the circuits in the manner in which they are to be used before the solution is added. In connecting them up, the lead strips forming the terminals of the positive and negative elements should be brightened at the surfaces that are to be in contact. The cells should be connected in series or in multiple, according to the use to which they are to be put, and in doing this great care should be taken that no cell is connected up the wrong way. The positive terminals on most makes of cells are marked, but they may be distinguished by the fact that there is always one less positive than negative plate in each cell. Moreover, the positive plates are usually of a reddish-brown color, while the negative plates are of a light drab. For each group of cells forming a battery, a double-pole, double-throw knife switch should be provided. The terminals of this switch connecting with the switch-levers should be connected with the terminals of the battery. The upper pair of terminals of the switch should be connected with the wires leading to the source of charging current, while the lower pair of terminals should be connected to the wires through which the storage-battery is to discharge.

64. Connections. — Storage-batteries for telephone work are nearly always arranged in duplicate, in order that one battery may be charging while the other is discharging. A simple arrangement of switches whereby either battery may be switched on to either the charging or discharging circuit is shown in Fig. 37, in which *B* and *B'* represent two storage-batteries, each consisting of seven cells in series.

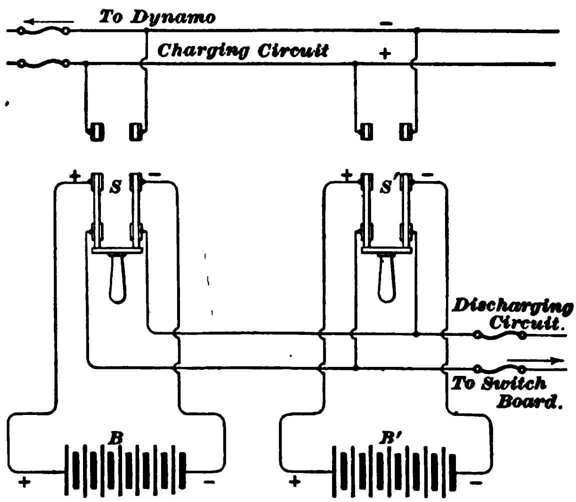


FIG. 37.

S and *S'* are double-pole, double-throw knife switches, the levers of which are connected, respectively, with the plus and minus poles of the batteries. The upper pair of contacts on each switch are connected with the positive and negative mains of the charging circuit, while the lower pairs are connected in a similar manner with the two sides of the discharging circuit. Both sides of each, the charging and discharging circuits, should be fused for a current slightly in excess of the maximum charge or discharge rate of the battery, and of course the wires in each of these circuits should be made of ample capacity for carrying these currents without undue heating.

65. Determination of Polarity.—The point of most vital importance in connecting up storage-batteries is that the positive lead of the charging circuit shall be connected with the positive pole of the storage-battery during charging. There are several easy ways of determining the polarity of a line, but perhaps the one that is least liable to produce error is performed by dipping the wires leading from each side of the charging circuit into a tumbler nearly filled with slightly acidulated water, as shown in Fig. 38.

FIG. 38.

A little of the solution from the storage-battery will answer this purpose well, or if this is not at hand, a tumbler of clear water with a pinch of salt thrown in will serve equally well. If the wires are held about an inch apart in the water, bubbles will rise from each, but at a much greater rate from one than from the other. The wire from which the bubbles rise in greatest profusion is connected with the negative side of the charging circuit, and that side should then be connected with the negative terminal of the battery. This method is dangerous with high potentials, and even with

110 volts should be used cautiously, unless there is considerable resistance already in the circuit besides that due to the solution.

66. Another method of determining the direction of the flow of current is by the use of a pocket compass held just over or just under the wire through which the current is flowing, as shown in Fig. 39. In this figure, *A B* is supposed to be a conductor carrying current. It should be

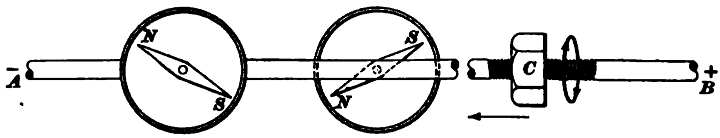


FIG. 39.

remembered that around this conductor will be a magnetic whirl consisting of lines of force in the form of closed curves. In order to clearly establish the relation between the direction of the lines of force and the direction of the current, a portion of the conductor is shown screw-threaded and engaged by a nut *C*. If the nut is turned in the direction shown by the arrows, it will move longitudinally along the conductor from right to left, and if turned in an opposite direction, its movement along the conductor will be from left to right. If the nut is considered to be turned in the same direction as the magnetic whirl, then its longitudinal direction will be the same as that of the current flowing in the conductor. The compass needle placed above or below the conductor, as shown, will be deflected in one direction or the other, and its north pole will be deflected in the direction in which the lines of force are rotating. By means of the compass, therefore, one can determine the direction of the magnetic whirl, and by the analogy of the right-handed screw-thread and nut one can readily determine the direction of flow of current. After the direction of the flow has been determined, it should be remembered that the pole from which it is flowing is positive, and this pole should therefore be connected with the positive pole of the storage-battery.

67. Solution for Storage Cells.—The solution for all commercial forms of storage cells consists of sulphuric acid and water, but the proportion recommended by different manufacturers varies to a slight extent. The best way to obtain the proper proportion between the acid and water is by means of a hydrometer, which usually consists of a small glass tube enlarged at one end and weighted with fine shot in the enlargement; one of these, commonly used for storage-battery work, is shown in Fig. 40. The tube when placed in the solution will float in a vertical position, and the more acid contained in the solution the higher it will float. By means of graduations on the small portion of the tube, the density can be determined with great accuracy.

FIG. 40.

68. Hydrometers.—There are two different methods of graduating hydrometers, the details of which need not be considered here. On one of these, known as the Nicholson or ordinary hydrometer scale, the density of water is taken as 1, or sometimes, for convenience, 1,000, while the density of sulphuric acid is 1.8, or sometimes 1,800. With this hydrometer, the proper density for the solution of most storage cells is 1.2 or 1,200, according to whether water is considered to have a density of 1 or 1,000. The other scale, known as the Baumé, is graduated according to an entirely different system, in which the density of water is 1° and the density of sulphuric acid 65°. The proper density of the acid for the storage-battery solution by means of the Baumé hydrometer scale is 25°.

69. Mixing the Solution.—A large earthenware vessel should be used for mixing the solution, as a considerable amount of heat is always generated when the water and acid are poured together, which is usually sufficient to break a glass vessel. The acid should be poured slowly into the water, and never, under any circumstances, should the water be poured into the acid, as the sudden heat generated is likely to cause the solution to be thrown violently in all directions. Too great emphasis can not be laid on the care in handling the concentrated sulphuric acid, as any carelessness in this direction may result in serious injury to the persons performing the work. It is well to have a bottle of strong ammonia close at hand in order to counteract any effects of the acid that happens to be spilled on the skin or upon other objects that it would injure. After the solution has been mixed, it should be allowed to cool and should then be poured by means of a glass funnel into the battery jars to such a height as to entirely cover both the positive and negative plates. Immediately after this is done, the charging current should be turned on, and should be of such strength as the directions accompanying the cell indicate. As the charging proceeds, the color of the positive plate will assume a dark-chocolate color, while the negative plates will retain their original lead color.

70. Determination of Condition of Cells.—There are several means of determining when a cell is fully charged: one is by the density of the solution, which should be about 1,200 on the ordinary hydrometer, or 25° on the Baumé hydrometer, or, in other words, about the same as that in the original charging solution. A better means of determining when a cell is fully charged is by means of a low-reading voltmeter placed directly across the terminals of each separate cell while the normal charging current is flowing. Under these circumstances, the voltmeter should indicate a pressure of 2.4 volts, and after the charging current has been turned off, the voltmeter should show a pressure of from 2 to 2.1 volts across the terminals of each cell. Discharging should not be continued after the density is lower than 1,150, or after the cells fail to show a terminal pressure of 1.8 volts each.

71. Charging.—The best way to charge storage-batteries is from a motor generator adapted to give the proper amount of current at the proper voltage. By this means there is very little waste of energy, as all the current sent out by the motor generator is used in charging the cells. Frequently, however, storage cells are charged directly from lighting mains, and the most usual plan is to place a rheostat in series with the cells, by which the proper amount of current will be allowed to pass through them. It, of course, would not do to connect a storage-battery of 7 cells in series directly across the mains of a 110-volt circuit, for then the amount of current passing through them would be excessive. Such a connection would, in fact, amount practically to a short circuit, as the resistance of such a battery is almost negligible and its electromotive force only about 14 volts. The most convenient rheostat is made of incandescent lamps, and a bank of such lamps may be constructed so as to allow the current to be graduated as desired. Such a lamp bank, constructed for a battery whose maximum charging rate is 5 amperes, is shown in Fig. 41. In this case, the charging current is

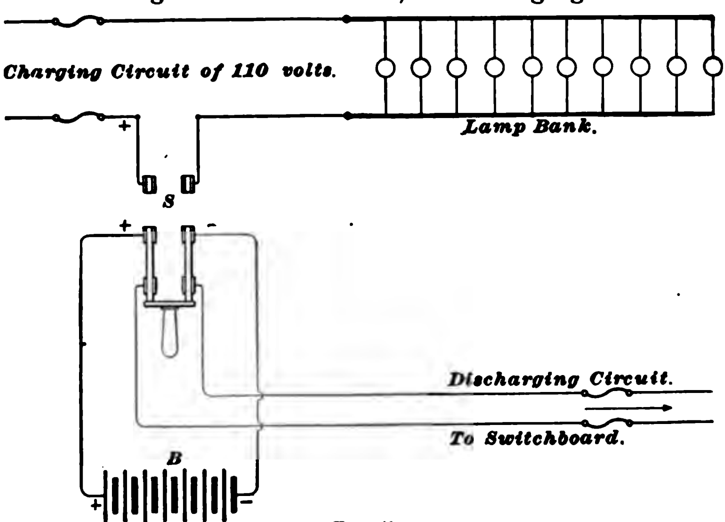


FIG. 41.

taken from 110-volt mains and led through the lamp bank and storage-battery in series. The lamp sockets are connected in multiple between the terminals of the bank, so that any number of the lamps, which are of the ordinary 110-volt sixteen candle-power style, may be connected in multiple in the circuit. As each of these lamps carries approximately ½ ampere at 110 volts, ten of them will give the desired maximum charging current, and therefore that number should ordinarily be used in charging. If, however, it is desirable to charge at a slower rate, the current may be graduated accordingly by turning on only one or more of the lamps. This form of rheostat is very convenient, for it enables the amount of current to be gauged with considerable accuracy.

72. This method of charging wastes a large amount of energy in the lamps, and as these lamps will burn, when connected as described, at almost their full candle-power, it will be seen that this amount of energy so lost may be an important item. A plan frequently adopted is to connect the storage-batteries directly in the lighting circuit of the house or building in which the exchange is located. In doing this, the battery should be connected in some circuit which carries a sufficient number of lamps to afford the proper charging current. If the presence of the storage-battery in this circuit is found to reduce the candle-power of the lamps to an appreciable extent, this can be remedied by using lamps of lower voltage on that particular circuit. The proper voltage for these lamps may be easily calculated by allowing for a reduction in voltage of two volts for every storage cell connected in series in the circuit. Thus, if the battery is composed of five cells connected in series, the voltage required for the lamps in that circuit will be 100 instead of 110. This is not a very desirable method.

BATTERIES FOR OPERATORS' TRANSMITTERS.

73. Individual-Transmitter Batteries.—In exchanges not using the common-battery systems for supplying current from a central source to all the subscribers' stations, several methods may be used for supplying current to the operators' transmitters at the central office. One of these, frequently used in small exchanges, is to make each operator's primary circuit entirely separate from all the others, and include in it about three gravity cells in series. This arrangement gives only fair results, and sometimes requires the maintenance of quite a large number of gravity cells. These cells are at best not well adapted for telephone purposes, on account of their high internal resistance. The internal resistance can be reduced by connecting two or more sets of three in parallel, requiring, of course, more cells.

74. Transmitter Circuits in Multiple.—The ordinary practice of the Bell Company now, and also of many of the independent companies, is to connect all the operators' transmitter circuits in multiple with the bus-bars leading from a storage-battery having very low internal resistance. This arrangement is shown in Fig. 42, in

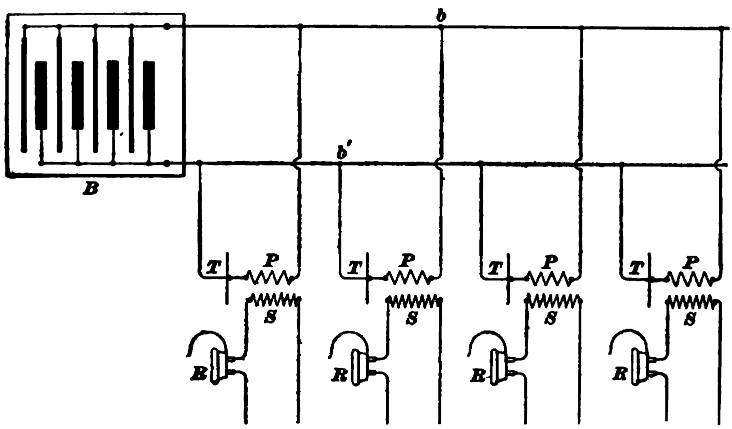


FIG. 42.

which B is the storage-battery, b and b' the bus-bars, T the transmitters, and P the primary coils of the various operators' circuits. The secondary coils S and the operators' receivers R are associated with the primary circuits in the ordinary way. Such an arrangement, if properly installed, will not produce cross-talk between the operators' circuits, and in order to bring about this desirable condition, two points must be considered: the first of these is that the storage-battery shall be of extremely low internal resistance; and the second is that the bus-bars shall be very short and of such a thickness as to render their resistance negligible. The reason for this is that if the resistance from the point on one bus-bar where the transmitter circuits join it, through the battery and to the corresponding point on the other bus-bar, is not very low, the difference of potential at these points *b*, *b'* will vary in unison with the current in that transmitter circuit, and consequently the current in another transmitter circuit will vary in turn with the difference of potential, causing, therefore, cross-talk in the second circuit. On the other hand, if the battery and the bus-bars are of sufficiently low resistance, then the difference of potential between *b*, *b'* will vary by an inappreciable amount, causing, therefore, inappreciable cross-talk in the second circuit. To further explain this, suppose that the total resistance of the bus-wires from *b*, *b'* to the battery and the internal resistance of the battery to be high, say 2 ohms, and the maximum and minimum current in the bus-bar, caused by the change in resistance in the one transmitter circuit connected to points *b*, *b'*, to be 1 and .999 ampere, respectively, then the change in potential at the points *b*, *b'* will be $2 \times 1 - 2 \times .999 = .002$ volt. Now, suppose that bus-wires so much larger are used that the total resistance is only .006 ohm, then the change in potential will be $.006 \times 1 - .006 \times .999 = .000006$ volt, or only $\frac{3}{1000}$ as great a fluctuation in the voltage at the terminals of the transmitter circuit as before. Consequently the fluctuating currents, and therefore the cross-talk, in another transmitter circuit will be only $\frac{3}{1000}$ as great in this case as in the first. In installing this system in exchanges of medium size, a storage-battery of a capacity of at least 100 ampere-hours should be used, and the bus-bars made of 000 trolley wire, not over 18 inches in length. Such a construction will give complete freedom from cross-talk, while with the same battery and the same number of transmitter circuits, bus-bars 6 feet long, of No. 3 wire, would cause much troublesome cross-talk.

PARTY LINES.

CLASSIFICATION.

75. A telephone-line having more than two stations upon it is called a party line. This definition probably needs a little explanation, as a line connecting two stations with a central office is a party line, and in order for the definition to hold good, the central office must be considered as one station. A party line may be defined as a line or pair of lines connecting two or more subscribers' telephones with a central exchange. The term "party line" is used in distinction from "private line," which may be defined as a line connecting a central office with one subscriber only, or one subscriber with one other subscriber only.

76. Party lines may be divided into two general classes: first, those upon which the bells of all the subscribers ring when a signal is sent to any one. In this, a code of audible signals is employed to enable the parties at the various stations to distinguish their calls from those of the other stations. These codes are usually made up of various combinations of long and short rings repeated a definite number of times, so that a party may at once by sound tell whether or not his attention is desired at the instrument. The second class embraces all those systems in which means are provided for ringing the bell of any subscriber on a line without disturbing any of the others. Systems arranged under this second class may be termed selective-signaling systems, in order to distinguish them from the systems of the first class, in which no means of selective signaling is employed.

NON-SELECTIVE PARTY LINES.

77. There are two general methods of arranging instruments on party lines. One of these is to place all the instruments in series in the line-wire, and the other is to connect them in multiple across the two sides of the line circuit. The first of these systems is called the series system, and the second the multiple or bridging system.

THE SERIES PARTY LINE.

78. Arrangement of Instruments on Series Lines. — The general arrangement of instruments on a series party line is shown in Fig. 43. In this, the various

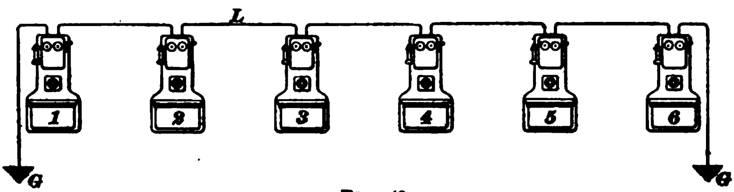


FIG. 43.

telephones *1*, *2*, *3*, *4*, *5*, and *6* are connected in series in a line-wire *L*, the terminals of which are grounded at the points *G*, *G*. This is a grounded series line, because the return is made through the ground. It would be termed a metallic-circuit series line if the return circuit were made through a separate wire instead of through the ground, as in this figure.

79. Circuits of Series Instruments.—The instruments used on such a line are the same as those used for ordinary exchange work, the circuits of which are shown in Figs. 87 and 89, *Telephony*, Part 1. In this form of instrument, it should be remembered that the ringer and generator are connected in series between the two line binding-posts of the instrument and that the generator is normally cut out by means of the shunt. When the receiver of any instrument is raised from its hook, the circuit containing the generator and call-bell is opened, while the talking circuit containing the receiver and the secondary winding of the induction-coil is closed between the same two binding-posts. It therefore follows that when two subscribers on such a line are talking, the circuit through their instruments will be through the talking apparatus, while that through all the other instruments not in use will be through the calling apparatus. Another good reason for cutting out the generator armature by means of the shunt may now be appreciated; for the resistance and impedance of these armatures, which is very high, would be difficult indeed to talk through on such a line. It is also obvious that the ringer magnets in instruments for this purpose should be of low resistance, in order that they may not unduly obstruct the passage of the voice currents.

80. Objections to Series Line.—On a line having six instruments, such as that shown in Fig. 43, if subscribers *2* and *5* were talking, the circuit would be completed through their talking apparatus and through the ringer magnets of instruments *1*, *3*, *4*, and *6*, and this inclusion of the ringer magnets of all idle instruments in the talking circuits is a necessary evil in the series system, inasmuch as these magnets must at all times, when the instrument is not in use, be left in the circuit in order that each instrument may at any time receive a call. The evil may be reduced to a minimum by winding the magnets to a low resistance and by cutting out the generators, as already stated; but even then it is a serious defect, and is not capable of giving the best service.

Besides this, such a line as is shown in Fig. 43 would be subject to serious disturbances caused by induction from other wires, or by earth-currents due to differences in potential of the earth at the two ends of the line. Inductive troubles on such a line may be largely reduced by using a complete metallic circuit, and this also will, if properly constructed, do away entirely with earth-currents. This, however, does not remove the evil effects of the ringer coils placed directly in the talking circuit, and only partially relieves the troubles due to induction from other wires, for it has been found that a proper balance can not be obtained between the two wires of a metallic circuit constructed on the series plan.

81. The generators for series lines are usually wound with a large number of turns of rather fine wire, for it is desirable for them to generate a high voltage with a comparatively small current. The ordinary generator for this purpose is wound with No. 35 or No. 36 B. & S. gauge, single silk-covered wire to a resistance of about 600 ohms. The ringers are frequently wound with No. 31 wire to a resistance of 120 ohms, but better results may be obtained by winding them with No. 30 wire to a resistance of from 60 to 80 ohms.

THE BRIDGED PARTY LINE.

82. Nearly all the early party lines were operated upon the series plan already outlined, but in 1890 Mr. J. J. Carty patented the bridging method of connecting telephones with the line circuit, which obviates many of the difficulties inherent in the series system.

83. Arrangement of Instruments on Bridged Line.—In Fig. 44 is shown a single-line wire *L* between

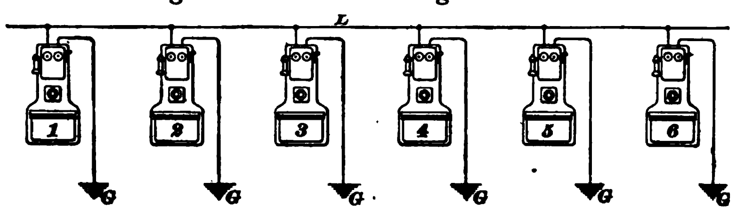


FIG. 44.

which and the ground *G* are bridged the various telephones *1*, *2*, *3*, *4*, etc. The instruments in this case are of the type shown in Fig. 90, *Telephony*, Part 1, in which it will be remembered the ringer magnets were bridged permanently between the two line binding-posts, this circuit being closed, whether or not the receiver was removed from its hook. In an entirely independent circuit, bridged between the same two binding-posts, is the calling generator, the circuit of which is normally held open either by a push-button or by an automatic circuit closer operating in much the same way as the automatic shunt on the ordinary telephone. Neither

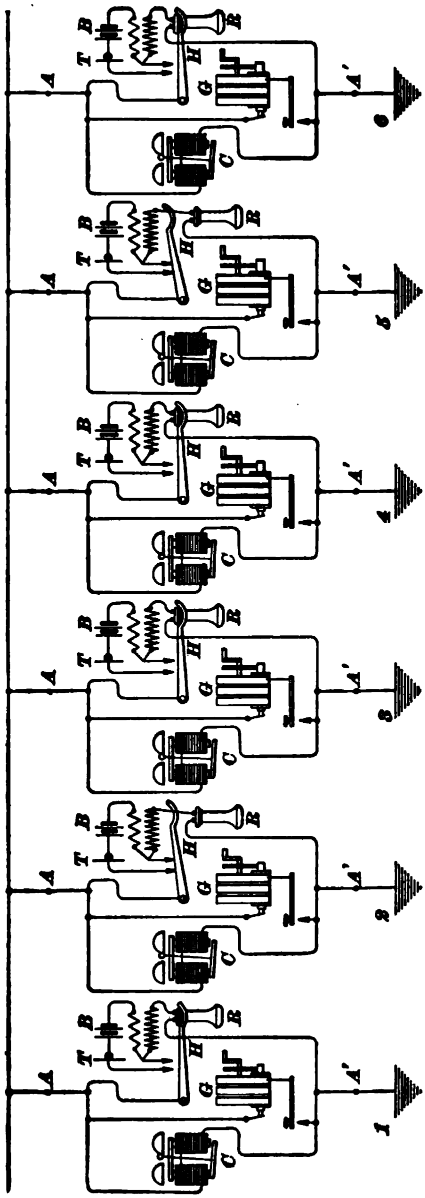


Fig. 45.

of these two circuits is controlled in any way by the hook switch. A third circuit exists in each telephone normally held open by the hook switch, and which is closed only when the hook is released from the weight of the receiver. This circuit contains the receiver and the secondary winding of the induction-coil in series, and is like the other two circuits connected between the line binding-posts. With the instruments connected between the line-wire and ground, as shown in Fig. 44, it will be clear that whenever the generator at any instrument is operated, the current from it will pass in multiple through all the ringer magnets on the line.

84. Operation of Bridging System.—The action of the bridging system may be more readily understood by considering Fig. 45, in which the circuits of six different stations are shown connected in multiple between a line-wire and the ground. The circuits are arranged in this diagram in a manner adapted to show very clearly the existence of the three bridged circuits between the two binding-posts *A* and *A'* of each instrument. When one station desires to call another, the generator circuit is closed either by a pressure upon the push-button, or, in better instruments, by an automatic device on the crank-shaft, while the generator is operated in the ordinary manner. The current from the calling instrument will divide, part of it flowing through the ringer *C* at the same station, and other parts passing in multiple through all the other ringers on the line. A certain number of rings will be given in order to designate the party for which the call is intended, and after that party responds, both remove their receivers from the hook in order to converse.

85. In Fig. 45, the receivers at stations *2* and *5* are removed from the hooks to permit conversation between them. At all the other stations the receivers are supported by the hooks, showing that these instruments are not in use. The voice currents generated at station *2* by the operation of the transmitter will pass over the circuit formed by the line-wire and the ground to the instrument at station *5*, through the talking apparatus of which they will pass, actuating the receiver in the ordinary manner. As the ringer magnet *C* at each of the stations is also connected between the line-wire and ground, it follows that each of them will form a bipath for these voice currents between the line-wire and ground. The leakage through these bells would be a very serious matter were it not for the fact that they are wound to a very high resistance, and in such manner as to present a great amount of impedance to the passage of the rapidly fluctuating voice currents. By this means, the leakage of the voice currents through these ringer magnets is rendered so small as not to be noticeable, and therefore they produce no undesirable effect upon the talking efficiency of the line.

86. Ringers.—The high retardation of the ringer coils is attained by using a somewhat longer spool than in the ordinary ringer, and winding it with a large number of turns of wire to a high resistance. The best construction for these ringers is to wind them to 1,000 ohms resistance, using No. 33, single silk-covered, magnet wire. Many companies, in order to obtain the desired resistance in a smaller space, wind these magnets with No. 38 wire to a slightly higher resistance, sometimes to 1,600 ohms. This, however, does not give as good results as the use of the No. 33 wire. The reason for this is that a No. 33 wire having a resistance of 1,000 ohms will be very much longer than a No. 38 wire having the same resistance. The No. 33 wire will, therefore, when coiled upon a magnet core, give a much larger number of turns on the magnet, and this is what is required to make the magnet have a high impedance.

87. Generators.—Generators for bridging instruments should be designed to produce a large amount of current rather than a high electromotive force. One reason for this is that they may have to supply current to call a number of bells arranged in multiple. It frequently occurs, also, that a high voltage as well as a large amount of current is needed, where it is desirable for each subscriber to be able to call all the others on the same party line. This is especially the case on long and heavily loaded iron lines, where a high voltage is needed to force the current through the line-wire to the more remote instruments. It not infrequently happens that generators which were designed for a series line are rewound with a larger wire in the hope of making them operate successfully on very long bridged lines. As a rule, these attempts result in failure, because when so rewound they do not generate a sufficient electromotive force to send enough current to the distant parts of the line. Under severe conditions, the ordinary series generator is not capable of sending out a sufficient amount of electrical power to meet the conditions, and the only remedy is to rebuild the line or equip it with generators made by some reliable firm, according to the most effective designs.

The winding of generators varies somewhat to meet different requirements. For ordinary copper line circuits a generator for bridging instruments wound with No. 33 wire to a resistance of 350 ohms gives good satisfaction. On short or low-resistance lines, the generator may be wound to furnish a low electromotive force which will not ring the bells on that circuit, but will operate a very low-resistance annunciator at the exchange, as explained in Art. **93.** Thus, all calls, even for other subscribers on the same circuit, must be made through the exchange. This is very desirable where a message rate is charged, so that a count of all calls can be kept and a loss of revenue avoided. In some cases, the Bell Companies use a generator whose armature coil has a resistance of 250 ohms.

88. Fig. 46 shows a complete bridging-bell telephone set, with the automatic *cut-in* device indicated in connection with the generator. The armature circuit is normally open between the spring *d* and the point *c*, but when the handle is turned, the spring *d* comes into contact with the point *c*, thus closing the circuit.

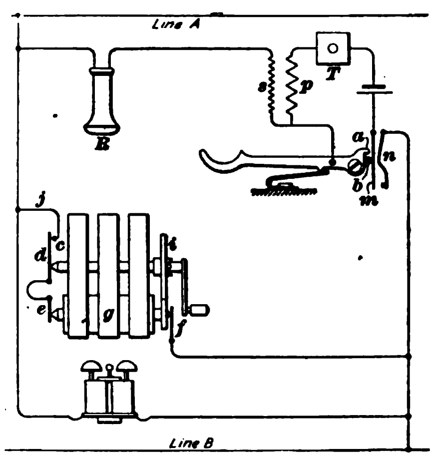


FIG. 46.

89. Induction-Coils.—The mistake is often made of using 500-ohm, or even 1,000-ohm, induction-coils on bridged lines. This practice tends to make the induction-coils at the two instruments in use present a very high impedance to voice currents, and to thus obstruct their passage through the talking circuits at these two instruments, which is exactly what is not desired. It is much better to use low-wound induction-coils, so that the voice currents sent over the line-wire will find a more ready path through the talking circuit of the station receiving at that time than through the call-bell bridges at the other stations. The use of induction-coils having secondary windings varying from 14 to 100 ohms is happily on the increase, and in no place are they of greater service than on bridged lines.

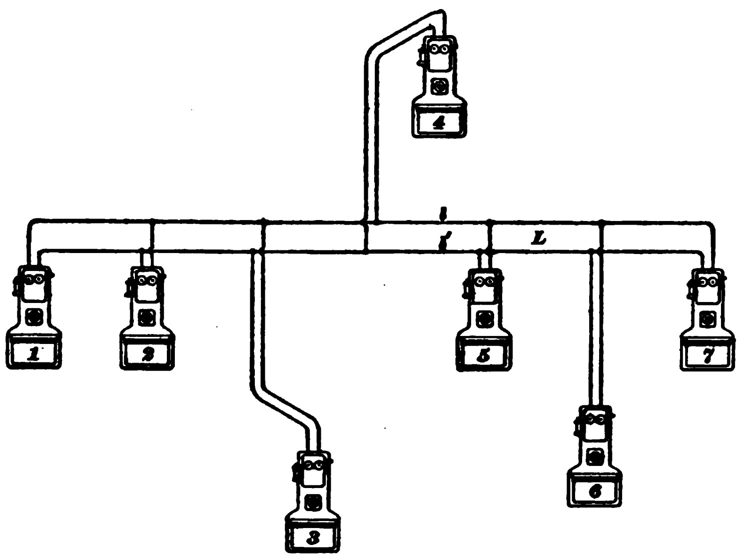


FIG. 47.

The greatest field of usefulness of the bridging principle is when applied to metallic circuits rather than grounded circuits. The principles are exactly the same, but instead of the binding-post *A'* of each instrument in Fig. 45 being connected to the ground, they are connected to a second line-wire, so that each instrument is bridged between the two sides of a metallic circuit. Such an arrangement is shown in Fig. 47, which shows seven stations bridged across the two sides *l* and *l'* of a metallic circuit *L*. The great advantage of this arrangement is that the adding of an instrument does not tend in any way to destroy the balance of the line. When branches of considerable length are run off from the main line, as is shown in case of instruments *3*, *4*, and *6*, each branch is in itself thoroughly balanced, and the two sides of the line circuit may be transposed as frequently as desired, in a manner to be described, in order to render the line absolutely quiet. The bridging system is now used on almost all the party-line work of the Bell Company, and is being adopted to a greater extent by the independent companies.

There is one distinctly beneficial effect obtained by the bridging system. The numerous cross-connections through the bells tend to free the line from electrostatic charges, and thus diminish indistinctness or cross-talk due to the capacity of the lines. This is of considerable importance where a ground return is used, as in Fig. 44, because the cross-connections also allow disturbances due to earth-currents and other external sources to escape to earth without all of it necessarily going through all the telephones. Consequently a grounded circuit with several bridging-bell connections may even furnish better service than it would with only one telephone station on it.

90. Modifications of the Carty System.—There are several modifications of the Carty system, in one of which the bell-magnet is cut out when the receiver is removed from the hook. This is accomplished by connecting the bell between one binding-post of the instrument and a bottom contact of the hook, the circuit being completed, when the hook is down, through the lever to the other line binding-post. The operation of this system is identical in every respect with the original Carty system, where the bells are permanently bridged between the binding-posts. It has the slight additional advantage of making one less bridge or leak circuit across the line for the talking currents, but the corresponding disadvantage of an additional contact point on the hook switch. Another modification, which is shown in Fig. 48, is one recently adopted by the Western Telephone Construction Company, and while it operates upon the same general principles as the Carty system, it is somewhat different in some of its details. In this figure, line *A* and line *B* are the two sides of a metallic-circuit line. The talking circuits are identical with those of the ordinary bridging instrument. The ringer

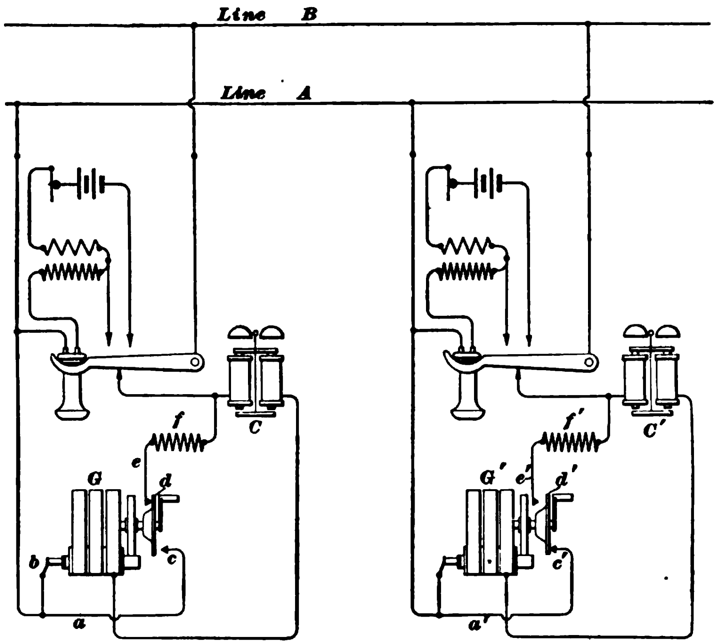


FIG. 48.

magnet *C* is connected in series with the generator armature, as in the ordinary series instrument, and the armature is itself normally shunted by means of the spring *c* engaging the disk *d* when the instrument is at rest. Connected between the lower contact point on the hook and the spring *e* is a small non-inductive coil *f*, having a resistance of approximately 100 ohms. This coil normally forms no part of the circuit, but when the generator crank is operated, the disk *d* is forced out of engagement with the spring *c* and into contact with the spring *e*, forming one terminal of the coil *f*. This breaks the shunt around the generator and sends the current from the armature directly to line through the coil *f* and the bell. The only function of the coil is to shunt enough of the current from the generator through the high-wound ringer coils *C* to cause the bell at the home station to ring. In Fig. 48 is shown the two possible connections of the generator, bell, and non-inductive coil. The right-hand part of the figure shows the normal position when the generator is not being used. In this case, the coil *f'* is on open circuit, the bell *C'* is connected through the frame of the generator, contact *c'*, and shunt wire *a'*, direct to line *A*, the armature being short-circuited by the wire *a'*. Thus, only the bell *C'* is connected across the lines *A* and *B*.

The left-hand portion of the figure represents the conditions when the generator is being used. In this case, the short circuit around the armature is opened at *c* and contact is made between the coil *f* and the generator by the spring *e*, so that the coil *f* and the bell *C* are now in parallel with each other but in series with the armature coil of the generator. This arrangement does away with the disadvantage of having the ringer magnet form a direct shunt to the generator at its own station, but has the disadvantage of adding about 100 ohms dead resistance to the circuit through which the generator is to ring. This amounts merely to the addition of a few miles of line-wire to the near end of the circuit, which may or may not be a serious disadvantage, according to whether or not the line is heavily loaded.

91. One decided advantage of this arrangement from the manufacturers' point of view is that the same instruments and the same wiring may be used for the bridged as for the series system. The only change necessary in transforming one of these instruments to a series instrument is to take out coil *f* and replace the magnets of the ringer by others having a resistance of not over 120 ohms.

CONNECTION OF PARTY LINES WITH SWITCHBOARDS.

92. Much trouble is frequently caused by connecting party lines with switchboards in an improper manner. A series party line should be brought into the exchange in the same manner as any other line, the line drop being of approximately the same resistance as the ringer magnets, i. e., about 80 ohms, and included directly in the circuit of the line. It should be so arranged with respect to the jack as to be cut out of circuit upon the insertion of a plug, in order that it will not be necessary to talk through it.

Under ordinary circumstances, a bridged line should have the drop connected directly across the two sides of the circuit in the same manner as the ringer magnets at the various instruments. The drop should be wound in such manner as to have a high resistance and impedance, and it is usually advisable to wind them to the same resistance as the ringer coils on the line. If, however, a tubular drop is used, such as is shown in Fig. 11, 12, or 13, *Telephony*, Part 2, a resistance of 500 ohms will usually be found sufficient, the iron core and shell increasing the impedance of the magnet to a sufficient extent to prevent the undue short-circuiting of voice currents. The drops may be left permanently bridged across the line in multiple with the jack, unless it is found that the presence of this permanent bridge cuts down the efficiency of ringing out over the line to the distant stations, in which case it is better to so arrange the drop that it may be cut out of circuit while ringing out. When left permanently in the line, however, it is useful to serve as a clearing-out drop.

93. Calling in One Direction.—On party lines terminating in an exchange, it is frequently desirable to so arrange the apparatus that the various stations can not call each other, but can call the central office. This may be accomplished on a bridged line by winding the switchboard drop to a very low resistance, and so arranging it as to be cut out when a plug is inserted. As a result, this drop will form a practically short circuit between the two sides of the line, and nearly all the current sent out from any subscriber's generator will flow through it instead of through the high-resistance bells. This plan gives good results on medium or short lines, but when used on very long lines, the resistance of the line-wire may be sufficient to shunt the current sent from the stations more remote from the central office through some of the ringer magnets nearest to them, thus causing them to ring. In order to prevent this, some companies now use bells wound as high as 2,000 ohms.

94. A more satisfactory method is to so arrange the polarized ringers that they will respond to currents in a certain direction only, and to provide commutators on the shafts of the generator armature at the subscribers' stations, so that the generator will send out pulsating currents in one direction only, that direction being opposite to that required for ringing the polarized bells. The switchboard drop bridged across the line at central may be of the non-polarized type and adapted to be thrown by currents in either direction. The central office generator may be of the ordinary type, giving alternating currents which, when sent over the line, will operate the bells of all the subscribers.

In the operation of this system, no subscriber can obtain a conversation with any other subscriber without the full knowledge of the operator, because the currents sent out by any subscriber's generator are in the wrong direction to ring the bells of any other subscriber. Such currents, however, will throw the switchboard drop and attract the attention of the operator, who can then call up the party desired, whether on the same or another line, in the ordinary manner. One method of arranging the armature of the polarized bell would be to attach a spring to one end of the armature in such a way as to normally pull it towards one pole when there is no current through the coils; but this spring must be weak enough to allow the armature to be drawn towards the other pole when the current flows in the proper direction. It is evident that if the end of the armature is held towards the negative pole, no effect will be produced upon the bell hammer by currents flowing over the line, which would tend to increase the strength of that negative pole, because the magnetism so generated would tend only to pull the armature closer to the pole against which it already rests.

LOCK-OUT SYSTEMS FOR PARTY LINES.

95. In the Carty party-line system previously discussed, there are two faults. In the first place, the operator can not ring one bell without ringing all the others, requiring a distinctive number of rings for each subscriber, and in the second place, no means are provided for preventing one subscriber from listening to whatever conversation is going on over the line between two other subscribers; and, further, there is nothing to prevent one subscriber from interrupting the conversation of others by turning his magneto-generator. These are somewhat grave defects, and lead to much trouble. They are not, however, serious enough to prevent the bridged party line, as described, from being used on most of the party-line systems in this country.

96. Mechanism of Scribner System. — Several kinds of lock-out systems have been devised with the idea of remedying these defects, and one of them, which is the invention of Mr. Charles E. Scribner, is shown in diagram in Figs. 49 and 50. Before considering the circuits, the construction of the lock-out box, shown in Fig. 49, will be described. This box, which is ordinarily mounted on the same backboard as the telephone instruments,

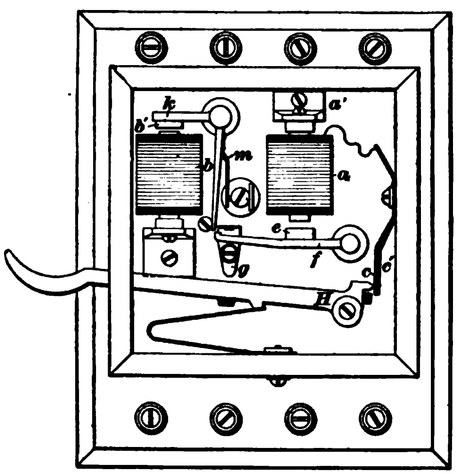


FIG. 49.

contains a hook switch *H* of the Warner type, having two contact springs *c* and *c'* (one behind the other), which make contact with the hook only when in its raised position. The arrangement is such that while the hook is rising, spring *c* will make contact with it slightly before spring *c'*. Within the box are two magnets *a* and *b*, of which *a* controls the continuity of the telephone circuits, and is therefore called the circuit-controlling magnet, and *b* controls a stop adapted to prevent the armature of *a* from being attracted, and is therefore called the stop-controlling magnet. The magnet *a* is mounted in a vertical position upon a bracket *a'*, and acts upon an armature *e* carried on a lever *f*, pivoted as shown. When the armature is attracted, the lever *f* engages a stationary contact *g* mounted on the backboard of the box, and the making of this contact, as will be seen later, closes the telephone circuit across the two sides of the line-wire. One terminal of the winding of the magnet *a* is connected with the contact spring *c'* of the hook, while the other is connected with one side of the line-wire. The magnet *b* is mounted alongside of the magnet *a*, and acts upon an armature *b'* carried on the short arm *k* of a bell-crank lever. This armature is normally held away from the magnet pole by a spring *m* resting against an adjustment screw, as shown. When the magnet *b* is energized, it causes the lower end of the bell-crank lever to move to the right against the pressure of the spring *m*, until it lies directly in the upward path of the lever *f*. From this it follows that if the magnet *b* is energized before the magnet *a*, the latter can not cause its armature *f* to make contact with *g*. One terminal of the magnet *b* is connected to the contact spring *c* of the hook, while the other is connected to that side of the line with which the magnet *a* is not connected.

97. Circuits—Scribner System.—The operation of the system as a whole may now be readily understood by reference to Fig. 50, which shows the circuits of four stations, *1*, *2*, *3*, and *4*, associated with the two sides *l* and *l'* of a metallic circuit connected with a spring-jack *J* and drop *D*

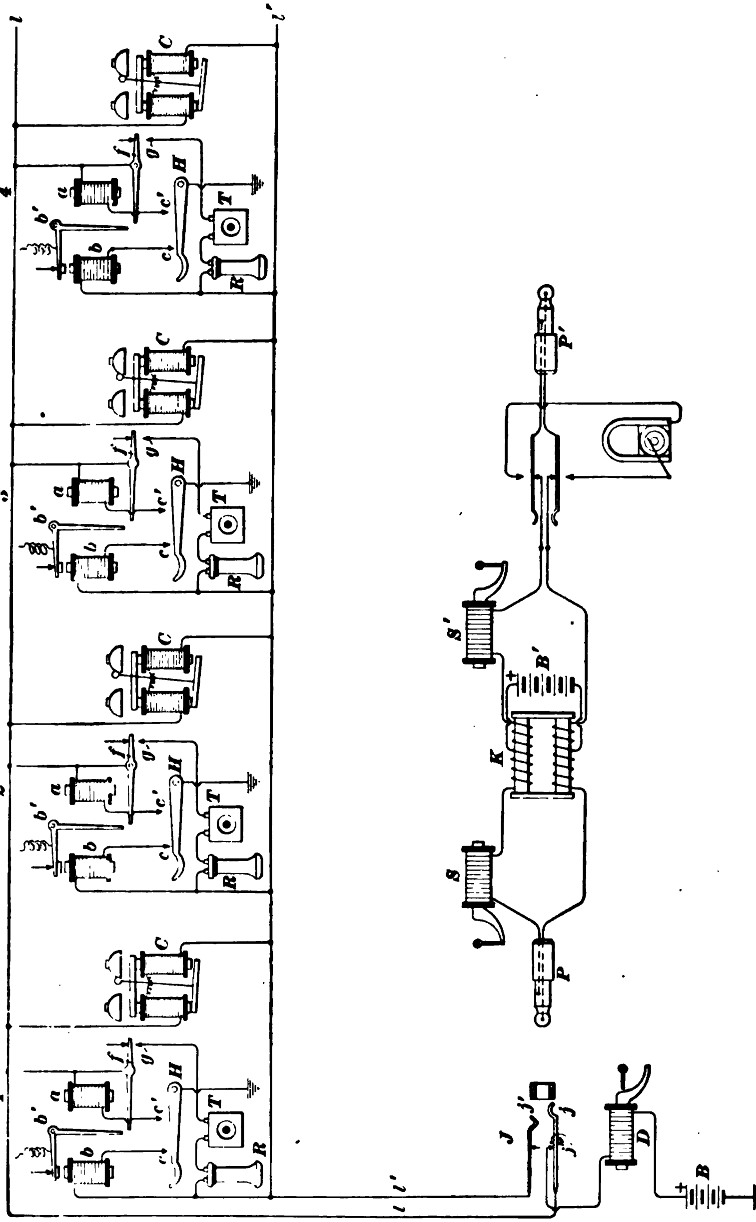


Fig. 50.

at central office. The mechanism at the subscribers' stations is shown in simplified form in order to better illustrate their connection in the circuits. The various letters used in connection with the lock-out mechanisms in Fig. 50 refer to the same parts as those used in Fig. 49. The circuit-controlling magnet *a* is connected between the line-wire *l* and the contact *c'*; the stop-controlling magnet *b* is similarly connected between the line-wire *l'* and the contact *c*. When the magnet *a* attracts its armature, the closure of the lever *f* against the contact *g* completes the circuit containing the telephone receiver *R* and the transmitter *T* across the two sides of the line, as shown. The polarized call-bell *C* at each station is permanently bridged across the line circuit, and is therefore made of high resistance and impedance to conform with the requirements of bridging-bell service.

At the central office is a spring-jack *J* having springs *j* and *j'* connected, respectively, with the line-wires *l* and *l'*. The spring *j* normally rests against an anvil *j"* connected with one terminal of the drop *D*, the other terminal of which is grounded through the battery *B*. A pair of plugs *P* and *P'* are shown connected together by a cord circuit and split repeating coil *K*, according to the Hayes system of common-battery supply. The battery *B'* is connected between the center points of the windings of the repeating coil, and furnishes current for talking, according to the methods already outlined. *S* and *S'* are supervisory signals connected, respectively, in the sleeve strands of the answering and calling plugs.

98. Operation—Scribner System.—Assume that subscriber No. *1* desires a connection with some other subscriber; he accordingly lifts his receiver from the hook, and as the lever *H* rises, it makes contact first with *c* and immediately afterwards with *c'*. As no battery is connected with the line-wire *l'*, the closure of the contact *c* produces no effect upon the magnet *b*, and therefore the stop-controlling lever is not operated. The closure of the contact *c'* establishes a circuit from the battery *B* over the line-wire *l*, through magnet *a*, contact *c'*, and to ground through the lever *H* back to the battery *B*. This causes the magnet *a* to close the contact point *g*, thus connecting the subscriber's telephone apparatus directly across the line. Should any other subscriber—for instance, No. *2*—now remove his receiver from the hook, the magnet *b* at his station will be energized, because the battery *B* is now connected with the line-wire *l'* through the telephone apparatus at station *1*. This circuit may be traced from the positive pole of the battery *B*, over line-wire *l* to station *1*, through the talking apparatus at that station to line-wire *l'*, thence to station *2*, and to ground through the magnet *b*, contact point *c*, and hook *H*; from the ground the circuit is completed to the negative pole of the battery *B*. The action of this relay, which occurs slightly before the magnet *a* at station *2* takes current, causes the stop-controlling lever *b'* to move in the path of the lever *f*, thus preventing its closing the telephone circuit at station *2* through the contact point *g*. A little consideration will show that the first party to remove his receiver from its hook thereby secures the entire control of the line until he has finished his conversation, this being brought about by the connection of the battery with the line *l'*, thus always assuring the operation of the stop-controlling magnet *b* at any other station when a second other subscriber removes his receiver from its hook. When the operator plugs in, the battery *B* is cut off at the contact point *j''*, but the battery *B'* is bridged across the circuit in its place. This battery *B'* supplies current to the talking apparatus in a manner already described, and also serves, as explained in the following article, to maintain the same condition with regard to the lock-out mechanism as did the battery *B*.

99. The circuit by which the stop-controlling magnet *b* is operated at any station after the plug *P* is inserted is a little difficult to grasp, but assuming as before that subscriber No. *1* is using the line and that subscriber No. *2* removes his receiver, the circuit may be traced as follows:

from the positive pole of battery *B'*, through the sleeve strand of the plug *P* to the sleeve spring *j* of the jack, thence by the line-wire *l*, through the magnet *a* at station *1*, to the contact point *c'* and to ground at that station through the hook lever. The circuit then passes through the ground to the hook lever *H* at station *2* (assuming that the party at that station tries to listen in), and by contact *c* through the magnet *b* to line-wire *l'*, which is connected with the tip spring *j'* of the jack. The circuit is completed through the tip contact and tip strand of the cord to the negative terminal of the battery *B'*. This circuit as just traced includes the stop-controlling magnet *b* at station *2*, causing that magnet to attract its armature, and thus prevent the operation of the armature lever *f* of the magnet *a*, with the result of locking out the subscriber. When the subscriber at station *1* finishes his conversation, he replaces his receiver on its hook; this breaks the connection that exists between the two sides *l* and *l'* of the line, and therefore stops the flow of current from the battery *B'* and allows the shutter of the supervisory signal *S*, which has previously been held in a horizontal position by the magnetic force of its core, to fall into the vertical position in which it is shown in Fig. 50.

100. Busy Signal—Scribner System.—As an improvement on the mechanism shown in Fig. 49, that shown in Fig. 51 has been devised, also by Mr. Scribner. In this figure, the various parts have the same letters of reference as the corresponding parts in Figs. 49 and 50, and are connected in the circuits in the same way. The bell-

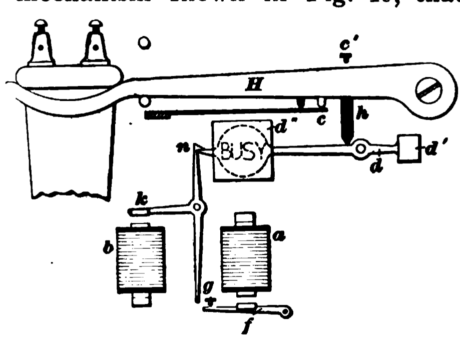


FIG. 51.

crank lever *k* of the lock-out magnet *b* carries on its upper end a hook or catch *n*, adapted to engage and hold down the long end of a lever *d* carrying a weight *d'* on its short arm and a target or signal *d"* on its long arm. The target *d"* is normally held down by the catch *n*, being forced into that position by the insulating lug *h* carried on the hook switch. When, however, any subscriber tries to use the line when it is already busy, the magnet *b* will attract its armature, thus locking out that station in a manner already described, and at the same time releasing the lever *d*. When this lever is so released, the weight *d'* will cause the signal *d"* to rise until it comes in front of an opening in the box, thus displaying the word "busy" to the subscriber. The subscriber therefore hangs up his receiver, thus causing the lug *h* to push the lever *d* into its normal position. This system, by preventing a second subscriber from cutting in on his line when it is already in use, overcomes only one of the objections to party lines. The other fault, i. e., the ringing of all the bells on a party line when the operator wants to call up only one station, is overcome by what is termed selective signaling.

SELECTIVE SIGNALING—PARTY LINES.

101. Selective-signaling systems for party lines may be divided into three systems, as follows: First, those employing step-by-step mechanisms operated by impulses of current from the central station in such manner as to close the calling circuits at the subscribers' stations successively; second, those using the harmonic or reed system of selecting, wherein currents of various frequencies are employed for actuating the different signals; and third, those using current of different strengths or of different polarities, or combinations of both, for operating the various signals.

STEP-BY-STEP SIGNALING.

102. The general plan used in step-by-step systems is that of employing a mechanism at each of the various stations on the line which will close a circuit at its station after a certain predetermined number of current impulses have been sent over the line. The mechanism usually consists of an electromagnet operating a pivoted armature, the armature acting by means of a pawl upon a ratchet-wheel to move the ratchet one notch for every attraction of the armature. Carried upon the ratchet-wheel, or connected with it by suitable gearing, is a contact arm so arranged as to engage a stationary contact at a certain definite point in its movement. This contact point is differently located on each instrument, so that when all the instruments are operated in synchronism, the circuits at the subscribers' stations will be closed one at a time. The arrangement on the line may be such that the contact lever of instrument No. *1* will engage its button after it has moved one step, that at No. *2* will engage its button after it has moved two steps, that at No. *3*, after three steps, and so on. In order to call any particular station—for instance, No. *10*—the operator would send ten current impulses over the line, which would bring the contact lever at station *10* into engagement with its button. Those levers at the stations having smaller numbers would have passed over their buttons, while those at stations having larger numbers would not yet have reached their buttons. After the completion of the circuit at the desired station, the operator then sends the ringing current over the line, which flows through the circuit completed at that station and sounds the bell of that subscriber only.

103. Faults of Step-by-Step Systems.—This general method of selective signaling appears to be a very promising one, but nevertheless has come into but little if any practical use, the difficulty being that it is almost impossible to secure proper electrical contacts between the stationary and movable contact points. Besides this, the step-by-step mechanism is always rather complicated—an undesirable feature, especially when in the hands of inexperienced parties

HARMONIC SIGNALING.

104. Every vibrating pendulum or reed has a natural period of vibration out of which it is a comparatively difficult matter to make it vibrate with any great amplitude. This fact is made use of in the harmonic selective systems by placing a reed or pendulum at each subscriber's station, adapted in each case to be acted upon by a magnet in the line-wire. The reeds at all the stations are tuned to vibrate at different rates, and when any one is thrown into vibration of the desired amplitude, it completes a circuit or circuits at that station, by which the signal is sounded. At the central office, transmitting devices or keys are provided, each adapted to send over the line circuit rapidly pulsating or alternating currents, the frequencies of which correspond to that of the reed at one of the substations. Thus, in order to call any particular station on a line, the operator, by means of one of the transmitting keys, sends a pulsating or alternating current of the proper frequency to line. The frequency of the impulses of this current being the same as the rate of vibration of the reed at the station which it is desired to call will throw that reed into motion and cause it to complete the calling circuit at that station. As none of the other reeds at the other stations have a rate of vibration corresponding to that of the particular current used, their reeds will not be thrown into vibration, or at least with sufficient amplitude, and their signals will remain inert.

105. Faults of Harmonic System.—The harmonic method of signaling has not proved a success, and there is but one or two such systems in operation in the United States. One reason for this is that it is very difficult to secure a good contact between a rapidly vibrating reed and a stationary contact. Another reason is that the adjustment of the rates of vibration of the various stations is so delicate that it is likely to be changed by variations in temperature or by other unavoidable causes.

STRENGTH AND POLARITY SYSTEMS.

106. As has already been stated, this class of systems relates to those in which signaling is accomplished by changes in the strength or in the direction of the current flowing in the line, or both. Although at first this general method seemed to present smaller possibilities than either the step-by-step or the harmonic method, it has come into wider use than either of those, and is now operating with entire success in many Bell exchanges. A relay with polarized armature and magnet cores can readily be made to respond to currents in one direction only. Obviously, this in itself on a single-line wire affords means for signaling either of two stations exclusively of the other, for one of the relays may be polarized to respond only to currents in a positive direction, and the other only to those in a negative direction. This idea, in combination with that of causing various magnets to operate in different manners when traversed by currents of different strengths, was used in many of the early attempts in this line of work, thus giving the name "strength and polarity" to the entire class of inventions. The successful systems, however, have depended almost entirely upon the changes in direction of current in the line, it having been found that to rely upon the strength of the current is in most cases unsatisfactory.

THE HIBBARD PARTY LINE.

107. Circuits.—In Fig. 52 is shown a party-line system devised by Mr. Angus S. Hibbard, which depends for its operation on the placing of two oppositely polarized bells between each side of a metallic circuit and ground. This system is arranged to operate upon the common-battery principle, both for talking and for signaling, but for the sake of simplicity the talking circuits have been omitted at the central office. *A*, *B*, *C*, and *D* are subscribers' stations, having talking apparatus consisting of receivers *R* and transmitters *T* adapted to be bridged across the two sides *a* and *a'* of a metallic-line circuit. Between the line-wire *a* and the

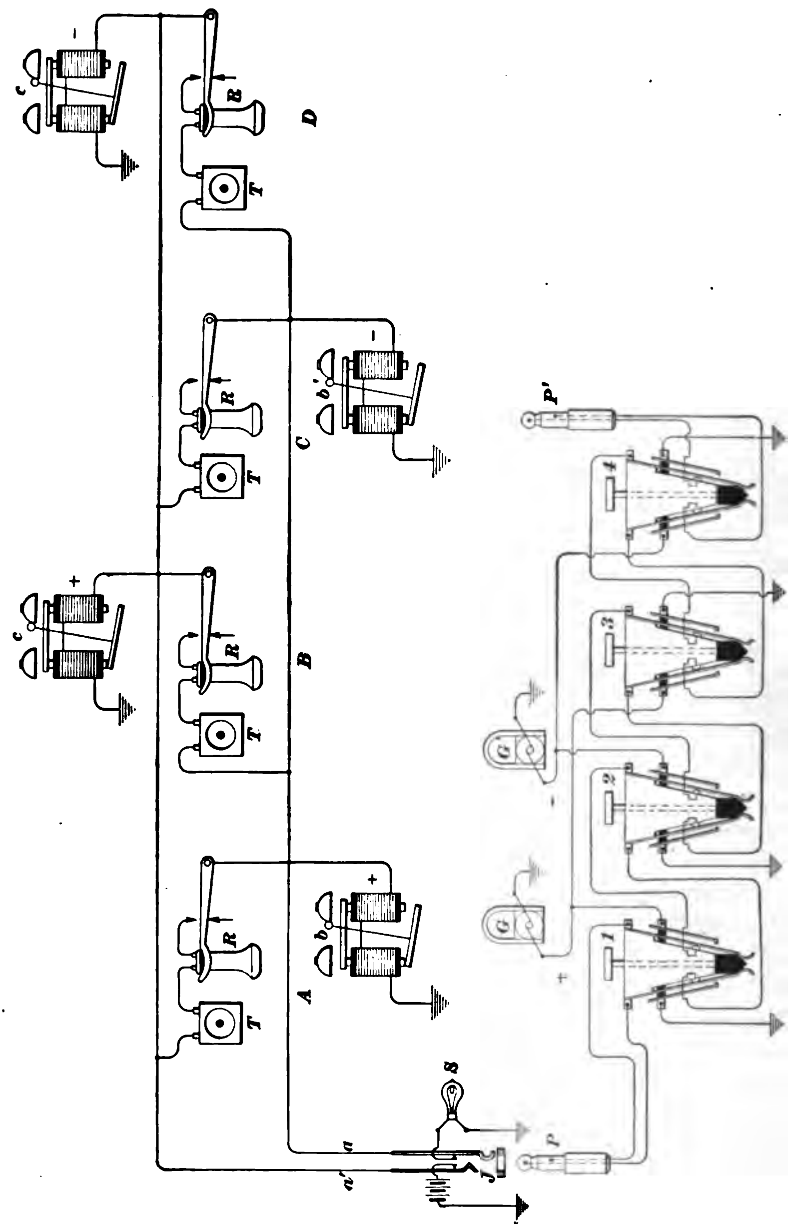


FIG. 52.

ground at station *A* is bridged a polarized bell *b* adapted to ring only on pulsating currents in a positive direction over the line-wire *a* with a ground return. At station *C* is connected in a similar manner a bell *b'* adapted to be rung only by currents in a negative direction. Connected between the line-wire *a'* and ground, at stations *B* and *D*, are polarized bells *c* and *c*. The bell *c* at station *B* is adapted to ring only by currents in a positive direction sent over the line-wire *a'*, using a ground return, and the bell *c* at station *D* will only be rung by negative currents sent over the same circuit. The side *a* of the line-wire is normally grounded at the spring-jack *J* at the central office through the signal *S*, while the other side *a'* is similarly grounded through a battery. When, therefore, any subscriber removes his receiver from its hook, the signal lamp *S* lights up.

108. Operation.—Connected with the cord circuit of the plugs *P* and *P'* are four ringing keys *1*, *2*, *3*, and *4*, adapted when depressed to connect one or the other of the call generators *G* and *G'* with one side or the other of the cord circuit. The connection of the various springs and anvils of these keys should be apparent from the diagram. It is readily seen that if key *1* is depressed, the positive side of generator *G* will be connected with the sleeve side of the cord circuit, and therefore with the side *a* of the line circuit, into the jack of which the plug *P* is inserted. When, therefore, this key is depressed, a current will pass from the positive terminal of generator *G* to the line *a*, from which it will pass to ground through the bells *b* and *b'*, located, respectively, at stations *A* and *C*. Only bell *b* will be rung, because its armature alone is polarized in the right direction to respond to positive currents. The bell *b'* will not ring, because it responds only to negative currents. Pressure upon key *2* will similarly connect the negative terminal of the generator *G'* with the line *a*, thus sending a negative current to that side of the line, which will operate the bell *b'* and not the bell *b*. In a similar manner, the keys *3* and *4* are adapted when depressed to send positive or negative currents to the line *a'*, thus ringing the bell at station *B* or station *D*, according to the direction of the current.

109. In some of the first systems operated on this plan, considerable trouble was experienced, due to the following cause: When a subscriber's receiver was removed from its hook, a low-resistance path was closed between the two line-wires at his station, and if at this time a signal was sent from the central office, it would ring a bell on each line. Thus, if the receiver at station *C* were removed from its hook and it was desired to call station *A*, a positive current would be sent over the line-wire *a*. This current would ring the bell at station *A* in a proper manner, but it would also pass through the talking apparatus at station *C*, to wire *a*, and then pass to ground through the bell *c* at station *B*, causing it to ring also. This trouble has been effectually removed in the system shown in Fig. 52 by causing the ringing keys to ground that side of the cord circuit which is not being connected with the generator. This prevents the ringing of a bell on the opposite side of the line by providing a shorter circuit to the ground at the central station through the other line-wire over which the current may pass instead of passing through the high-impedance bells. To illustrate this, the case may be again assumed where it is desired to ring the bell at station *A*, while the receiver of station *C* is off its hook. Key *1* will be depressed, which will send current over the line *a* and ring the bell *b* at station *A*. Some current will pass through the talking apparatus of station *C* to the line-wire *a'*, but instead of this current passing through the magnets of bell *c* at station *B* or *c* at station *D*, it will return through line *a'* to the central office and pass to ground through the short circuit at the key.

THE BARRETT-WHITTEMORE-CRAFT SYSTEM.

110. One of the most successful systems for selective signaling on party lines adapted for a greater number of stations than four has been devised by Messrs. Barrett, Whittemore, and Craft, and is in extensive use in connection with many Bell exchanges. It depends for its operation on the sending of currents in either direction over either or both sides of a metallic-line circuit, in combination with each other or the ground.

111. Principles of Operation.—The fundamental principles upon which the operation of the system depends

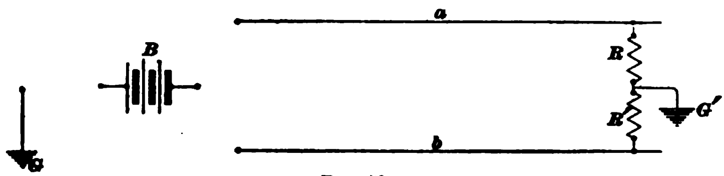


FIG. 53.

is shown in Fig. 53, in which *a* and *b* represent the two sides of a metallic-circuit line, and *R* and *R'* the coils of two relays at a subscriber's station, *R* being connected between the line *a* and the ground *G'*, and *R'* between the line *b* and the ground *G'*. *B* is a battery at the central office and *G* is the central office ground. By using the ground as a third conductor, four different circuits may be obtained from the central office. One of these includes the line-wire *a* with the ground return; a second, the line-wire *b* with the ground return; a third, the line-wires *a* and *b* as a metallic circuit, not using the ground circuit at all; and a fourth, the line-wires *a* and *b* in multiple with the ground return. The battery *B* at the central office could be connected by a proper manipulation of switches in any one of these four circuits, and each of them would include one or both of the relay magnets *R* and *R'*. Obviously, these four circuits obtained from the two conductors and the ground might be used for obtaining four selective signals from the central office to the various subscribers' stations, all equipped with relays *R* and *R'*. If, now, one or both of the relays *R* and *R'* is polarized, the number of possible selective signals obtainable is doubled, for the battery *B* could then be connected so as to send its current in either direction through

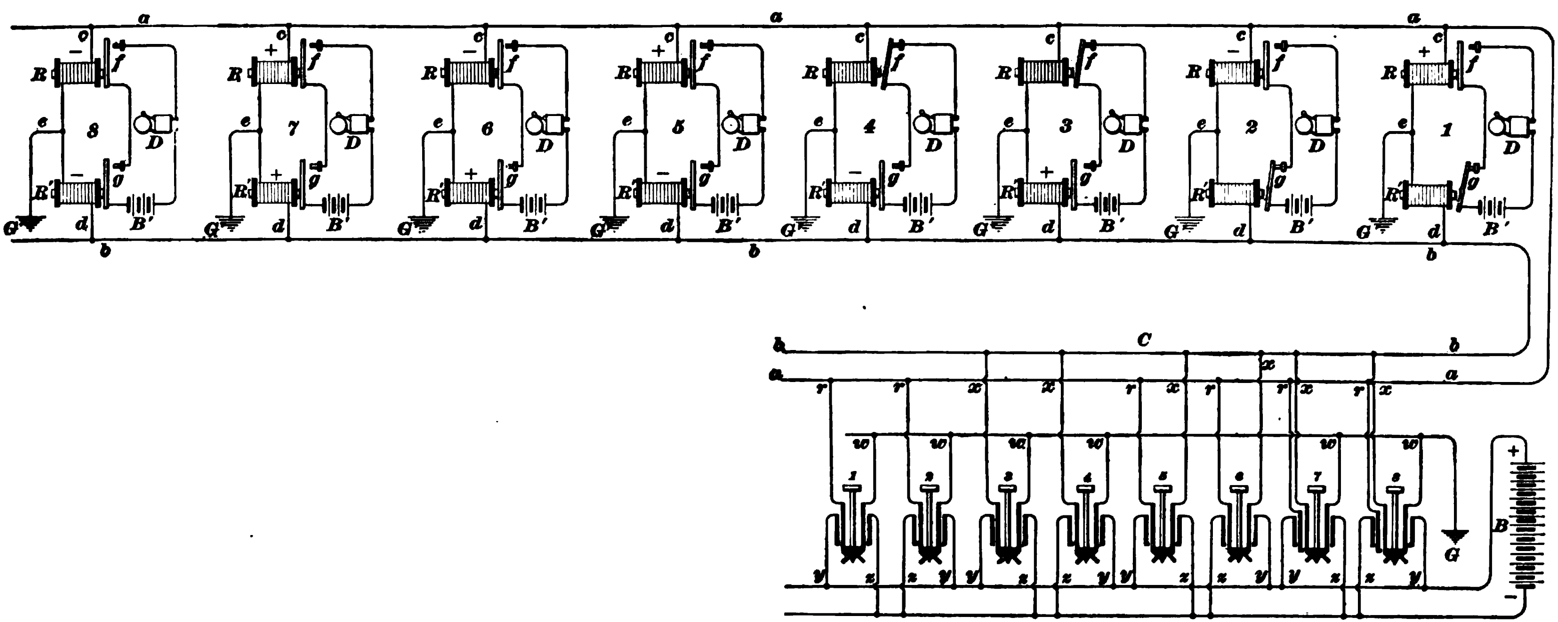


FIG. 54.

any one of the four circuits mentioned. It is by means of these four available circuits, and by a proper choosing of the direction of current through them, that selective signaling is brought about in the Barrett-Whittemore-Craft system. For convenient reference, the following table is given for the eight different combinations used for transmitting signals in this system:

CURRENT COMBINATIONS.

	Line *a*.	Line *b*.	Ground.
1	+	0	−
2	−	0	+
3	0	+	−
4	0	−	+
5	+	−	0
6	−	+	0
7	+	+	−
8	−	−	+

In the first combination, the line *a* is used with the ground return, the positive pole of the battery being connected with *a* and the negative with the ground. In the second combination, the same circuit is used, but the battery reversed. By following through the table, it will be seen that the combinations therein given correspond with those mentioned above, there being four different circuits, each having current sent over it in two directions.

112. Simplified Circuits.—In Fig. 54 is shown in simplified form a metallic-circuit line having eight stations, *1*, *2*, *3*, *4*, etc., connected at the central office *C* with eight ringing keys, also numbered *1*, *2*, *3*, *4*, etc., the numbers of the keys corresponding to those of the stations. At each subscriber's station are two relays, *R* and *R'*, placed in ground branches *c* and *d*, between the line-wires *a* and *b*, respectively, and the ground. These two branches are united at the point *e*, which is connected with the earth at the point G'. A vibrating call-bell D is placed in a local circuit at each station, this circuit including also the battery B' and the contact points and armatures of the two relays R and R' in series. Unless, therefore, both relays have released their armatures so as to close the local circuit at the points *f* and *g*, the bell D can not ring.

Although all the relays are connected to the line circuit in exactly the same way, the arrangement of relays at each of the stations differs in some respect from that at all the others. Part of the relays are non-polarized or neutral, so that their armatures, which *normally close their local contact* points, will be attracted by currents in *either direction and their contact points opened.* The other relays are polarized in such manner as to *normally hold their local circuits open, except when energized by currents in the proper direction to cause them to release their armatures.* The polarized relays are marked + and − in Fig. 54, the sign in each case meaning that the relay magnet will release its armature when traversed by a current of the corresponding polarity, but under no other conditions. A current which flows from the line-wire to ground at the subscriber's station is in each case considered +, that flowing from the ground to the line-wire being considered −.

113. Effects of Current Combinations on Relays. —By referring now to the table of Current Combinations, it will be found that any one of those combinations will serve to close the local circuit at one station, and at one only. Take, for instance, combination No. 1, which calls for a positive current over line-wire *a* and no current at all over line-wire *b*. This current will cause the relay R at station *1* to release its armature and close the circuit there, and there being no current in line *b*, no effect will be produced upon the relay R', the armature of which is already against its contact. The local circuit will thus be closed at both points, and the bell at that station will ring. The bell at station *2* will not ring, because a + current over line *a* will not operate the relay *R*, it being negatively polarized. Station *3* will not respond, for the + current over wire *a* will cause the neutral relay *R* to attract its armature, thus breaking its local circuit at *f*. Station *4* will not respond for the same reason; station *5* will not respond because the relay *R′* will maintain the circuit open, because it requires a negative current through it to close its circuit, even though the relay *R* will close its circuit upon the passage of the positive current. Station *6* will not respond for the same reason that station *2* did not; i. e., because it requires a negative current in *R* to close its circuit, and also for the reason that there is no current on the line *b*. Station *7* will remain quiet because there is no current to operate the armature *R′*, and at station *8* neither armature will be affected, by virtue of the current in the wire *a* being in the wrong direction and of the absence of current in the wire *b*.

114. By following through each of the current combinations, it will be found that combination No. 2 will close the local circuit at station *2*, combination No. 3 that of station *3*, and so on throughout the entire number, no combination serving to ring the bell of more than one station. At the central office *C* there is a battery *B*, from the positive and negative bus-bars of which lead wires *y* and *z* to the outer contact springs on the ringing keys. The inner contact springs of these keys are connected either with the line-wires *a* or *b* by wires *r* or *x*, respectively, or with the wire leading to the ground *G* by wires *w*. The arrangement of each key is such that when depressed it will connect the battery with the line-wires or the ground wire in the manner necessary to bring about the proper current combination. To illustrate this, if key *1* is depressed, the positive pole of the battery is connected by wires *y* and *r* with the line-wire *a*, while the negative pole is connected by the wires *z* and *w* with the ground wire. No connection is made with line-wire *b*, which therefore receives no current. This, it will be seen by reference to the table of Current

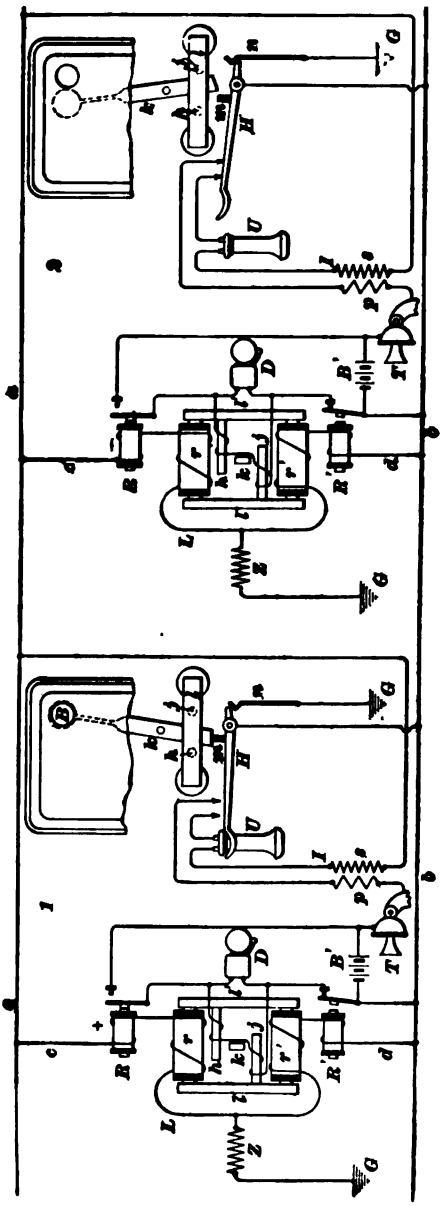


Fig. 55.

Combinations, is the proper combination to actuate the bell at station *1*. Keys *7* and *8* are each provided with one more spring than the other keys, so that when one of them is depressed, the two line-wires *a* and *b* will be connected together and with one terminal of the battery, while the remaining terminal of the battery is grounded. This is necessary for sending the 7th and 8th combinations, in which the line-wires are used in multiple as one side of the circuit, the ground forming the other side. In Fig. 54, the talking apparatus, as well as the switchboard jack and drop, are omitted in order to render the ringing circuits more clear. In connecting the talking apparatus with the line-wire under this arrangement, it would only be necessary to bridge it across the line circuit in the ordinary manner, having the circuit normally open while the receiver is upon its hook, but closed when it is removed therefrom.

115. By the arrangement thus far described, all the available current combinations are used for operating selective signals at eight different stations. In order, however, to secure a reliable means for locking out the instruments of all the subscribers on the line except the one who is actually using it, two of the current combinations—the 7th and 8th—are reserved for controlling the locking and unlocking mechanisms. This leaves but six combinations for signaling purposes, and this system is therefore usually equipped for that number of stations.

116. Complete Station Circuits.—In Fig. 55 is shown the complete circuits of two stations provided not only with the relays R and R', the local battery B', and the bell D, but also with the lock-out apparatus L, the hook switch H, and the talking apparatus, consisting of the transmitter T, the induction-coil I, and the receiver U. The lock-out mechanism L consists of two coils r and r', wound upon cylindrical soft-iron cores, the ends of which are joined by soft-iron yoke pieces l and l', which, together with the cores, form a closed magnetic circuit of rectangular form. Projecting from the inner sides of these yoke pieces are two soft-iron polar extensions h and j, between which plays a pivoted polarized armature k. This arrangement is shown in plan view at the left-hand portion of each substation circuit in Fig. 55, and in side elevation in the right-hand portion of each substation circuit. The lever k carries at its upper end a "busy" signal marked B, which, when the lever is drawn towards the pole h, is displayed in front of an opening in the instrument box to show that the line is busy. The coils r and r' are connected, respectively, in the ground branches c and d containing the relay windings R and R'. The coils r and r' are so wound that for any of the six current combinations used in calling the various stations, the lines of force set up in the cores of the coils will be in the same direction in the rectangular magnetic circuit. That is, the magnetomotive force which set up the magnetic lines of force are in series, and the cores of coils *r* and *r'* and the yoke pieces *l* and *l'* form a continuous magnetic circuit of low reluctance for these lines of force.

117. Effects of Current Combinations on Lock-Out Mechanism.—If, as in the current combination used to actuate station *1*, a positive current is sent over the line-wire *a*, magnetism will be generated in the core of coil *r* only, and this magnetism will be practically short-circuited by the yoke pieces *l* and *l'* and the core of coil *r'*. Very little polarity will therefore be developed in the polar extensions *h* and *j*, which will therefore exert no influence upon the polarized bar armature *k*. The same will be true with regard to each of the first four current combinations, because they involve the sending of current through one of the coils only. With combination No. 5, in which a positive current passes through the coil *r* and a negative current through the coil *r'*, a north pole will be developed at the right-hand end of the core of the coil *r* and at the left-hand end of the core of coil *r'*. With combination No. 6, the reverse of this condition will take place, and in either case, very little polarity will be developed in the polar extensions *h* and *j*, because the magnetomotive forces developed in coils *r* and *r'* will be in series in both cases, and the direction of the lines of force set up by each coil will be the same in the yokes and cores, and the path will have such low reluctance that practically none of the lines will stray out through *h* and *j*. The lever *k* will therefore not be affected by either of these combinations. When, however, combination No. 7 is used, a positive current will flow through both the coils *r* and *r'*. This will develop a positive polarity at the right-hand end of both cores, thus giving the entire yoke bar *l'* a positive polarity and the bar *l* a negative. The polar extensions *h* and *j* receive the full benefit of this magnetization, causing the former to become strongly positive and the latter strongly negative. This combination acts upon the polarized bar *k* to pull its lower end towards the left, and thus display the busy signal, as shown at the right-hand portion of station *1*, in Fig. 55. When combination No. 8 is used, the left-hand yoke bar *l* is positively and the right-hand yoke bar *l'* negatively magnetized, thus making the polar extensions *j* and *h*, respectively, positive and negative. This serves to move the lever *k* in the opposite direction from that to which it had been moved by combination No. 7, this position being shown at the right-hand portion of station *2*, in Fig. 55.

118. When the lever *k* is moved by current combination No. 7, the busy signal is not only displayed, but the lower end of the lever passes over a lug *m* on the hook lever *H* in such manner as to prevent the hook from rising should it be released from the weight of the receiver. Thus, when combination No. 7 is sent over the line, the apparatus at all the stations except the one already in use will be locked out, the lever *k* preventing the hook from rising to complete the circuits of the talking apparatus in the ordinary manner. The transmitter *T* is connected in a local circuit with the battery *B'* when the hook is raised, this local circuit also containing the primary winding *p* of the induction-coil *I*. The secondary circuit, containing the receiver *U* and the secondary *s* of the induction-coil, is at the same time closed across the sides *a* and *b* of the line, as in the ordinary bridging system.

119. Windings on Polar Extensions.—The windings on the polar extensions *h* and *j* are connected in series, forming a shunt around the vibrating bell *D* at each station. The object of this is to prevent the locking out of the station which is to be called; for when the operator at central presses key *7* for operating the locking-out devices, all the locking levers *k* on the line, including that of the party to be called, will be actuated. When a current combination is sent over the line for the purpose of calling one subscriber, the relays at that station will be operated to

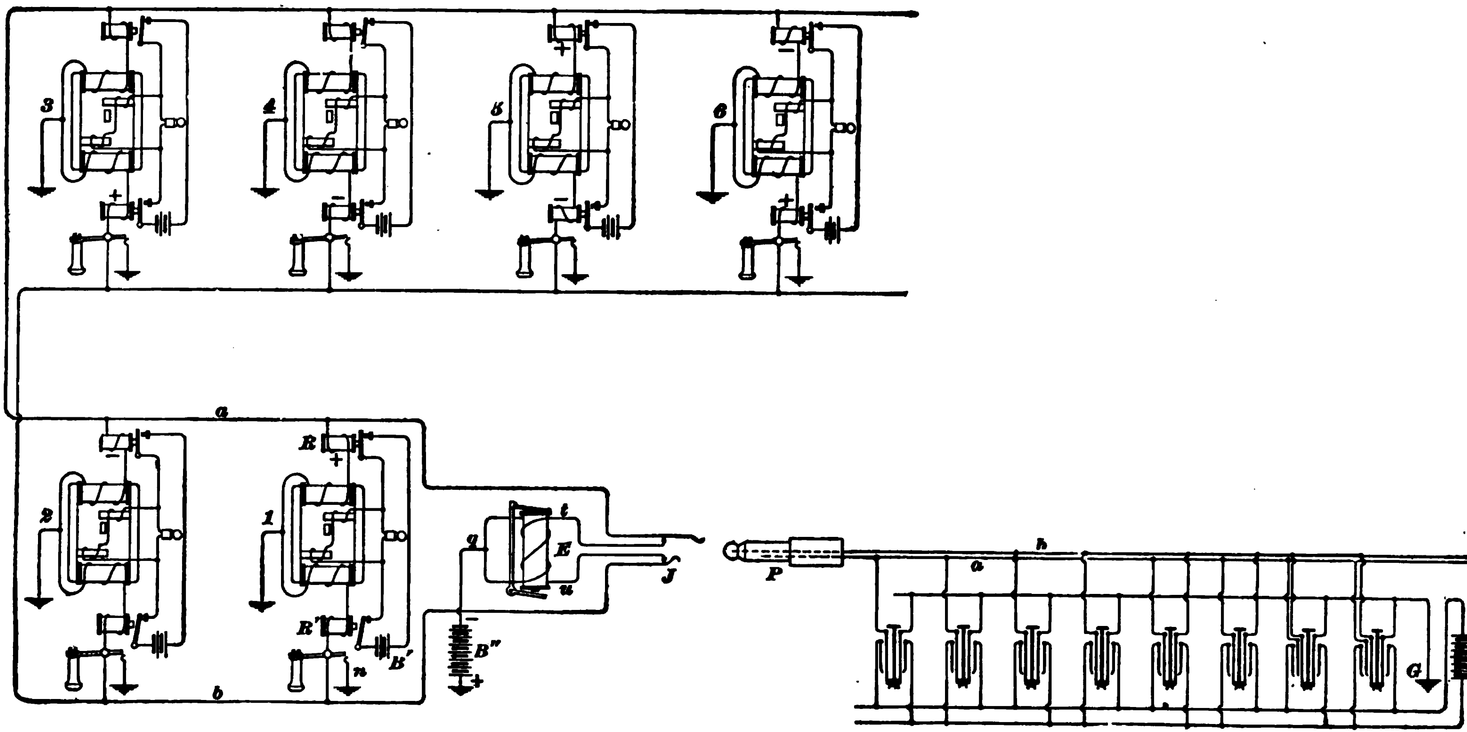


FIG. 56.

close the local circuit, and part of the current flowing in this circuit from the battery B' will be shunted by the coil of the bell D through the windings on the polar extensions h and j, and this current flows in such a direction as to move the locking lever k out of the position into which it was moved by the locking combination. The windings on these polar extensions, therefore, have no function except at the station that is being called.

120. Operation as a Whole.—The operation of this system as a whole may be understood from Fig. 56, which shows six substations provided with the apparatus already described and connected between the line-wires a and b, which terminate in a spring-jack J at the central station. The two springs of this jack are connected, respectively, with the terminals of two windings t and u on a drop E. These windings pass around the drop in opposite directions with respect to currents passing over the line in multiple, and have their opposite terminals connected together at the point q, which is grounded through the battery B''. This drop is not affected by currents passing from the battery B'' through its windings and over the two sides of the line circuit in parallel, because the magnetism generated in its core by one winding is neutralized by that of the other. The negative pole of this battery is connected to the point q, and this, during the period of disuse of the line, is equivalent to combination No. 8, and therefore holds all the polarized armatures k in the unlocking position. When, however, the plug P is inserted into the jack, the annunciator and battery B'' are disconnected from the circuit at the spring-jack, and the operator may send whatever current combination she desires over the line.

121. In order to call central, the subscriber has only to remove his receiver from its hook. The short end of the hook lever in its downward path encounters the end of the spring n, which momentarily closes a short circuit from the line-wire b to ground. This allows a relatively large current from the battery B'' to flow through the winding u of the drop, which produces a magnetizing effect on the core greatly in excess of that produced by the small current flowing through the winding *t*, the line-wire *a*, and leaking to ground through the various *R* relays. The core of the drop is therefore energized and the signal displayed. The operator inserts the plug *P* into the jack, and after listening in with the ordinary listening key, she connects the line with any other, in the usual manner. When one of the substations on a line is to be called, the plug is inserted into the jack and key *7* depressed; this sends a positive current over both sides of the line in parallel, which operates to lock the apparatus at all the stations, without ringing any of the bells. The key bearing the same number as the subscriber to be called is then depressed, which results in ringing the bell at that station and at the same time releasing the lock-out apparatus by the local circuit, which is shunted around the vibrating bell *B* at that station. The subscriber called then removes his receiver from the hook and engages in conversation, but the subscribers at all other stations are kept from listening in or in any way interrupting the conversation because their switch-levers are held down by the locking lever *k*, Fig. 55. This system represents probably the highest development yet obtained in selective signaling on party lines.

FUTURE OF SELECTIVE SIGNALING.

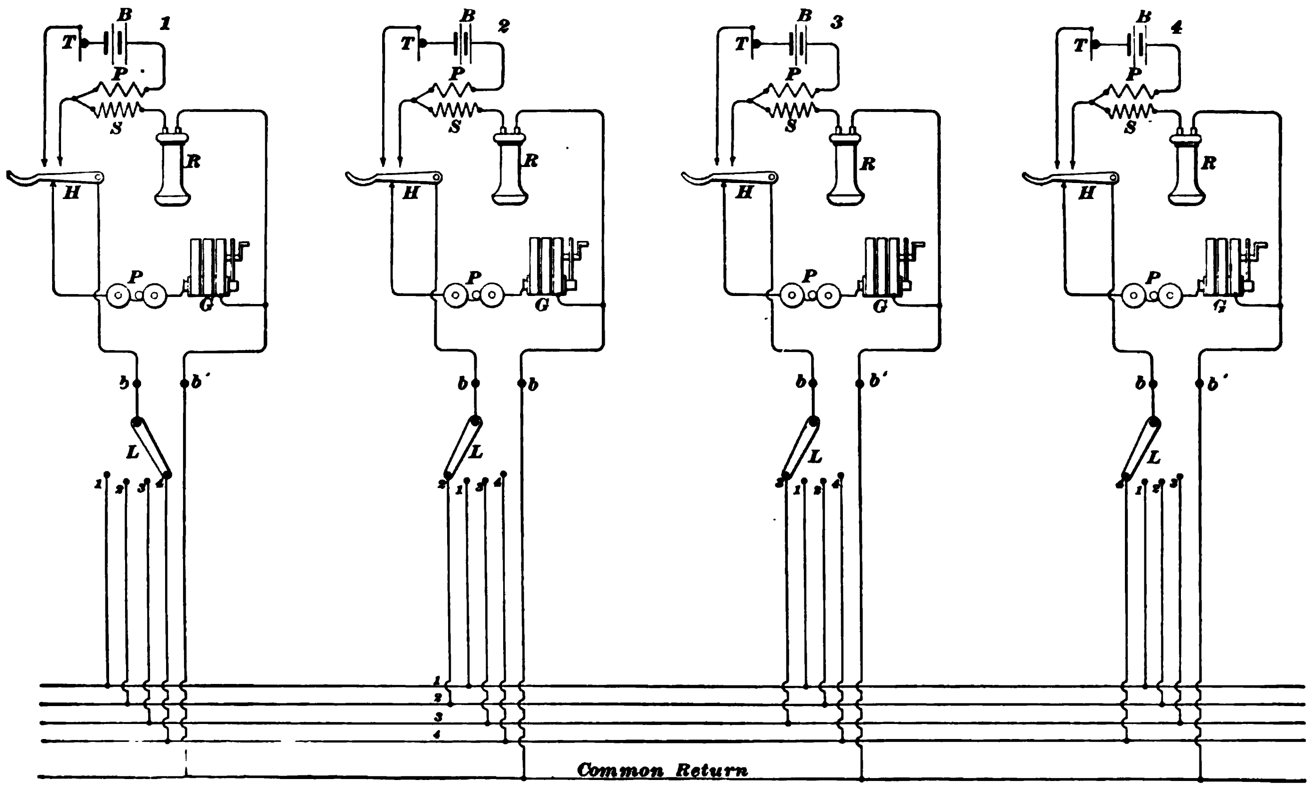
122. Although the advantages of selective signaling on party lines have been for many years recognized, its use has not become at all general until within the last three or four years. The reason for this is that the systems devised in the early days of telephony were totally inadequate to meet the conditions of practical work. There is, however, in all localities a demand for cheap service among a certain class of people, and the best way of furnishing a reliable service at a low rate is by placing the subscribers on party lines and providing means not found in the ordinary bridging system, for calling one without interfering with the others.

The Hibbard system, with many modifications, and also the Barrett-Whittemore-Craft system are rapidly coming into use for furnishing this class of service, and the success of their work when properly attended to warrants the conclusion that their use will become far more general.

SYSTEMS REQUIRING NO OPERATOR.

THE HOUSE SYSTEM.

123. Circuits.—Two general plans may be followed in installing telephone systems in buildings: one is to run a separate circuit from every station to a switchboard placed at the central office, and any of the switchboard systems adapted for small exchanges already described may be used for this purpose. The other plan is to run a wire from each station through each of the other stations, and to provide a switch at each station whereby the instrument at that station may be connected with the wire belonging to any other station. This system is known under several names, among which are the intercommunicating system, the house system, and the speaking-tube system. This system, which will throughout this work be called the house system, has one distinct advantage for very small exchanges over the switchboard system in that it does not require the service of an operator to make connections between the subscribers as desired. Such a system in its simplest form is shown in Fig. 57. At the top of this figure are shown four subscribers' stations, numbered *1*, *2*, *3*, and *4*. Each of these consists of an ordinary telephone set, consisting of talking apparatus and a magneto-generator and the ordinary polarized bell. Below each telephone is a switch-lever *L*, usually mounted on the backboard of the telephone set and adapted to slide over and make successive contacts with the buttons *1*, *2*, *3*, and *4* beneath. Four line-wires run



B
1
T
P
S
R
H
P
G
b
b'
L
1
2
3
4
B
2
T
P
S
R
H
P
G
b
b
L
2
1
3
4
B
3
T
P
S
R
H
P
G
b
b'
L
3
1
2
4
B
4
T
P
S
R
H
P
G
b
b'
L
4
1
2
3
1
2
3
4
Common Return

FIG. 57.

through each station, each bearing a number corresponding to the number of the station which it represents. Each line-wire is permanently connected with the buttons bearing the same number at each station. On each switch the button bearing the same number as the station to which that switch belongs is placed at the left-hand end of the row, and is called the home button. Thus, at station *3* the button marked *3* is placed at the left-hand end of the row of buttons, instead of occupying its regular place in the sequence of numbers. The system of electrical connections is in no wise affected by this, the button being merely shifted from the position it would ordinarily occupy. One terminal *b* of the telephone set is connected by a short wire with the pivot of the lever *L*, the other terminal *b'* being connected with a common-return wire running through all the stations in parallel with the line-wires.

124. Operation.—The operation of this system is very simple. All the levers are normally placed on the left-hand or home button. When, however, one station desires to call another, the party at the calling station moves the lever on his telephone to the button bearing the number of the station he desires to call. This act switches his telephone upon the line belonging to the subscriber with whom he desires a connection. He then operates his call generator in the usual way, and after the subscriber has responded, the two converse by the ordinary methods over the line-wire bearing the number of the called station, and the common-return wire. As shown in Fig. 57, the lever *L* at station *1* has been moved to button *4* in order to call station *4*; and by tracing the circuits, it will be found that these two stations are now connected in a metallic circuit formed by the line-wire *4* and a common-return wire.

125. Disadvantage of Ordinary House System.—The fact that the calling party must always return the lever *L* to the home button when through a conversation brings about considerable trouble in this system, and people not accustomed to its operation will constantly forget to do this, thereby leaving the instrument in connection with the line of another party. To illustrate this, if subscriber No. *1* leaves his switch-lever on button *4* after finishing his conversation, it will be impossible for any other station to call No. *1* by the ordinary method, for the instrument of No. *1* is no longer connected with line *1*, as it should be. Moreover, if any one desires to call station *4*, the bells at both No. *4* and No. *1* will ring, thus bringing about much confusion.

HOLTZER-CABOT HOUSE SYSTEM.

126. Automatic Switch.—This feature has been remedied in a few systems, the means adopted in most

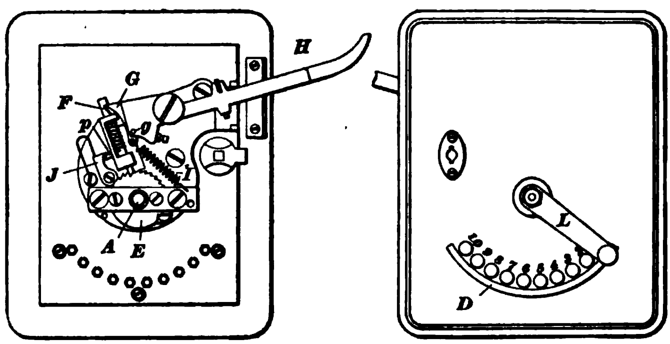


FIG. 58.

cases being to provide mechanism by which, when the receiver is hung up, the switch-lever will be automatically restored to the home button. Fig. 58 shows a switch provided with mechanism for accomplishing this result. This particular automatic switch is manufactured by the Holtzer-Cabot Company, and has proven thoroughly reliable in practice. The lever *L* is adapted to slide over the various buttons *1*, *2*, and *3* in a manner already indicated, it making contact always with the one over which it lies. The curved contact piece *D* is so arranged that the lever will not normally engage it, but by pressure upon the handle of the latter, the two may be brought into electrical contact. *H* is the hook switch adapted to perform various changes of circuit, as indicated later. The lever *L* is mounted upon a shaft *A* passed through the front board of the box, which shaft carries a ratchet-wheel *E* of hardened steel. A coiled spring around the shaft tends to rotate it, so as to bring the lever always to the home position. *F* is a sliding pawl normally held in its lower position by a coiled spring surrounding it. This pawl is therefore adapted to retain the lever in any position to which it has been moved, by engagement with any one of the teeth on the ratchet-wheel. *G* is a dog of hardened steel, pivoted at *g* on the short arm of the hook lever. This dog is pressed into engagement with a notch *F* by the spring *I*, one end of which is secured to the frame of the mechanism. When the lever *L* is moved into contact with any one of the buttons on the front of the box, the ratchet *E* is turned with it and is held from turning back by the pawl *F*. If, then, the receiver is removed from the hook, the dog *G* passes downwards and into the notch of the pawl, it being allowed to slide over the surface of the pawl by virtue of its flexible connection at the pivot *g* with the hook lever *H*. When the user has finished his conversation, he hangs up his receiver, and the upward movement of the short end of the hook lever causes the dog *G* to raise the pawl *F* out of engagement with the ratchet-wheel. At the extreme upper limit of the short arm of the hook, the dog *G* is withdrawn from the notch, so as to allow the pawl *F* to again come in contact with the ratchet-wheel, in order to be in position to engage it when the lever arm *L* is next moved.

In order that the ratchet-wheel and the lever may be given sufficient time to move back to the normal position, a small auxiliary dog *J* is provided, which passes under a pin *p* on the pawl when the latter is raised, and holds the pawl in its raised position until the lever arm reaches the home button, when a pin on the lower surface of the ratchet moves the dog *J* out of engagement with the pin *p* and allows the latter to drop into the home notch of the ratchet-wheel.

127. Circuits.—In Fig. 59 the connections of the apparatus used with this system are shown in detail at stations *1* and *4*. In each of these, *M* is the transmitter, *B* the local battery, *P* and *S*, respectively, the primary and

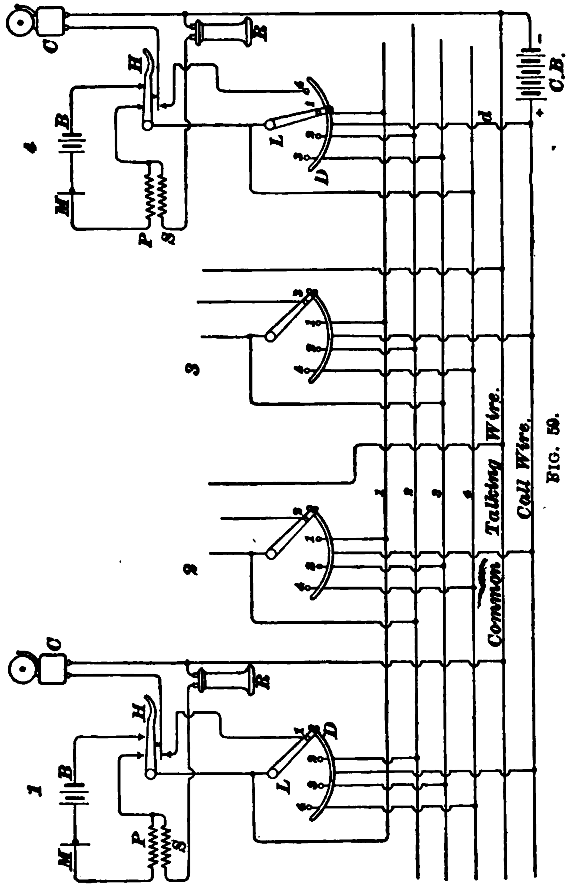


FIG. 59.

secondary windings of the induction-coil, *C* the vibrating call-bell, and *R* the receiver. In the position shown, station *4* is supposed to be calling station *1*, and for that purpose the lever *L* is moved into contact with button *1*, all the levers at the other stations being in engagement with their respective home buttons. When the handle of lever *L* at station *4* is depressed against the curved contact *D*, the bell at station *1* is rung. The circuit through the call-bell at station *1* may be traced from the positive pole of the battery *C. B.* through the wire *d* to the curved contact *D* at station *4*; thence by means of the lever *L* to button *1* at station *4*, with which that lever is in contact; thence by wire *1* to the lever *L* of the switch at station *1*; thence by the button *1* and through the lower contacts of the switch hook to one terminal of the bell *C*.

128. The return circuit is made by means of the common talking wire to the negative pole of the call battery. When both parties remove their receivers from the switch hooks, the primary circuits are closed in the ordinary manner. The secondary or talking circuit may be traced from the secondary winding *S*, at station *4*, through the receiver *R* to the common talking wire; thence through the receiver *R* and secondary *S*, at station *1*, to the hook lever *H*, and thence by wire *1* to station *4* and through button *1*, switch-lever *L*, switch hook *H*, and back to the secondary coil at station *4*.

129. Plug Switch for House Systems. — Some manufacturers, instead of using the rotary switch described in the foregoing house systems, use a flexible cord and plug in place of the switch-lever, and sockets or jacks into which the plug may be inserted, instead of the buttons. This arrangement has some advantage over the switch-arm-and-buttons principle, due to the fact that a well-made plug and jack insures better contact than that usually obtained by the mere contact of a switch arm upon a button. The rotary switch, however, is adapted to give good service if properly made, and there is little choice between them.

ANOTHER HOUSE SYSTEM.

130. The system about to be described avoids some of the objections mentioned in Art. **125**, but does not make use of an automatic switch, as in the Holtzer-Cabot system.

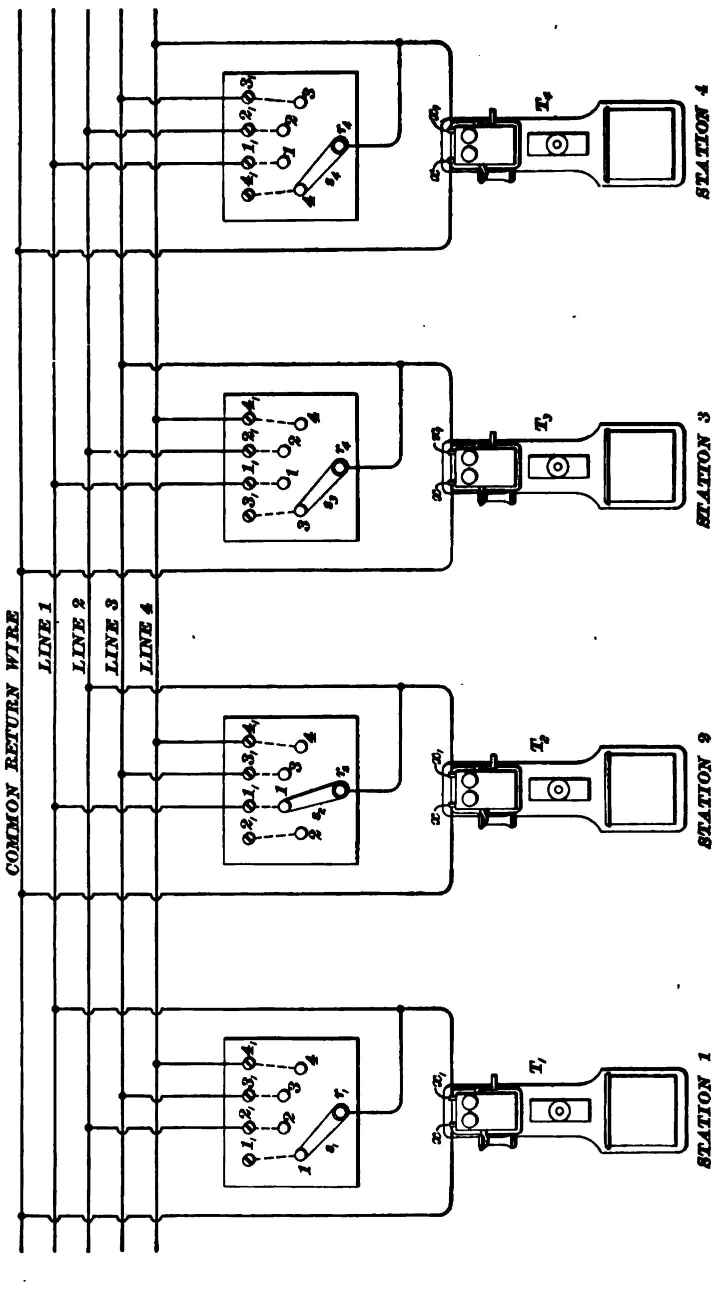

COMMON RETURN WIRE
LINE 1
LINE 2
LINE 3
LINE 4
STATION 1
STATION 2
STATION 3
STATION 4

FIG. 60.

131. Magneto-Call System.—Fig. 60 shows a diagram for four stations, but the system can, of course, be extended to include any larger number. *T* is the usual telephone set, as sold by the manufacturers, complete with transmitter, induction-coil, receiver, hook switch, local microphone battery, magneto-generator, and polarized bell. At each station that point of the switch which corresponds in number to the number of that particular station is not connected with any other point or wire, although the connecting arm of the switch *s* normally rests upon it. This is the normal or home position of the arm *s*, to which it should always be returned when through using the telephone. To insure uniformity at all instruments, the home position should be the first one on the left, as shown at each station.

If all the switches *s* are in their normal positions, i. e., on their home contacts, it will be found that the circuit of each instrument is open at its own contact point on every selective switch, and no bell can be rung by turning any generator handle. If station *2* desires to call station *1*, it will be necessary to first move the switch arm s_2 at station *2* to contact point *1*. If the generator at station *2* is turned before doing this, neither bell at station *2* nor any other bell will ring, supposing, of course, that all switch arms are resting on their home positions. This silence will indicate to the person at station *2* that he has not turned his switch at all. If, however, he first turns his switch s_2 to point *1* and then operates his generator, both his bell and the bell at station *1* will ring, but no others. The path of this ringing current will be as follows: From the generator at station *2* to its binding-post x_1, to switch s_2, to binding-post 1_1, line *1*, binding-post x_1, bell, and binding-post x at station *1*, to common-return wire, to binding-post x, bell and generator at station *2*. Thus both bells will ring, but as all other bell circuits are open, none of the others will ring. Similarly, by turning switch s_2 to point *3* or *4*, station *3* or *4* will be called up, respectively. In the same manner, a party at any station can, by turning the switch there to the proper position, ring up any desired station. Suppose No. *2* goes away from his telephone without returning the switch from point *1* to its home position, let us see what will happen. It is quite evident that No. *1* can ring up No. *2* without touching his switch, and if he does move his switch to point *2*, he will still ring only No. *2*. If No. *1* desires to call up No. *3*, and moves his switch s to point *3* and turns his generator, both telephones, T_2 and T_3, being in parallel with each other, will cause the current from the generator at station *1* to divide between them, and therefore, in addition to his own bell, those at stations *2* and *3* will also ring. If both parties answer, some confusion may arise, but No. *1* can easily dismiss the one not wanted and continue his conversation with No. *3*.

If, as before, No. *2* leaves his switch arm s_2 on point *1*, and station *4* desires to call up No. *3*, the only bells to ring when No. *4* puts his switch s_4 on point *3* and turns his generator will be his own and that at station *3*. This can be determined by the reader himself, by tracing out the closed circuit. If the number of stations were larger than given in the figure, it could be shown that if one switch is on some point other than its home position, say, for instance, that switch s_2 is on contact *1*, then any station other than No. *1* or No. *2* can ring up any desired station without calling up any other, but can not call up either No. *1* or No. *2* without ringing both those bells.

If, while No. *1* is talking to No. *2*, No. *3* can also call up No. *4* without interfering in any way with No. *1* and No. *2*, it follows that No. *1* and No. *2* can be talking together at the same time that No. *3* and No. *4* are conversing. So, on a system having a large number of stations, all the telephones can be in use at the same time in sets of two. Of course this will not warrant putting too many stations on one system, for other reasons. Furthermore, the telephones can never be left in a position entirely useless, on account of the position of the hand switch s.

The telephones, switches, and the wires running through the building should be connected exactly as shown in

Fig. 60. One binding-post x at the top of each telephone is connected to the common-return wire, the other binding-post x_1 to the pivot r of the switch arm s and to its own particular line-wire. That is, at station *1*, x_1 is connected to line *1*; at station *2*, x_1 is connected to line *2*; and so on at all stations. The binding-posts 2_1, 3_1, and 4_1, at station *1*, are connected to lines *2*, *3*, and *4*, respectively. Similarly, at station *2*, binding-posts 1_1, 3_1, and 4_1 are connected to lines *1*, *3*, and *4*, respectively. It should be noted that binding-post 1_1 at station *1*, binding-post 2_1 at station *2*, 3_1 at station *3*, and 4_1 at station *4* are not connected to anything.

132. Battery-Call System.—A system similar to the preceding, but using a common battery for ringing up the telephone stations, is shown in Fig. 61. The connections are very much the same as for the magneto-generator call system shown in Fig. 60, and the manner in which the system operates is the same, except that instead of turning a generator handle, the push-button switch is pressed in order to ring the bell at another station. The push-button switch is so made that it normally connects its pivot c_1 with a contact point a_1, but when depressed it connects the pivot c_1 with the contact point b_1. The common battery for calling or ringing purposes is connected at any convenient point to the common-return and the battery wires. When the push-buttons at all stations are in their normal positions against the upper contacts a_1, a_2, etc., the common battery is on open circuit. If, however, one push is depressed, say p_2, and the switch arm s_2 is on point *1*, then current will flow from the common battery $C\ B$, through the battery wire, contact b_2, pivot c_2, binding-post x, telephone T_2, binding-post x_1, pivot r_2, arm s_2, contact point *1*, binding-post 1_1, line *1*, and at station *1* through binding-post x_1, telephone T_1, binding-post x, pivot c_1, contact a_1, common-battery wire, and, finally, back to the common battery $C\ B$. Thus, both bells at stations *1* and *2* will ring as long as the push-button p_2 is held down.

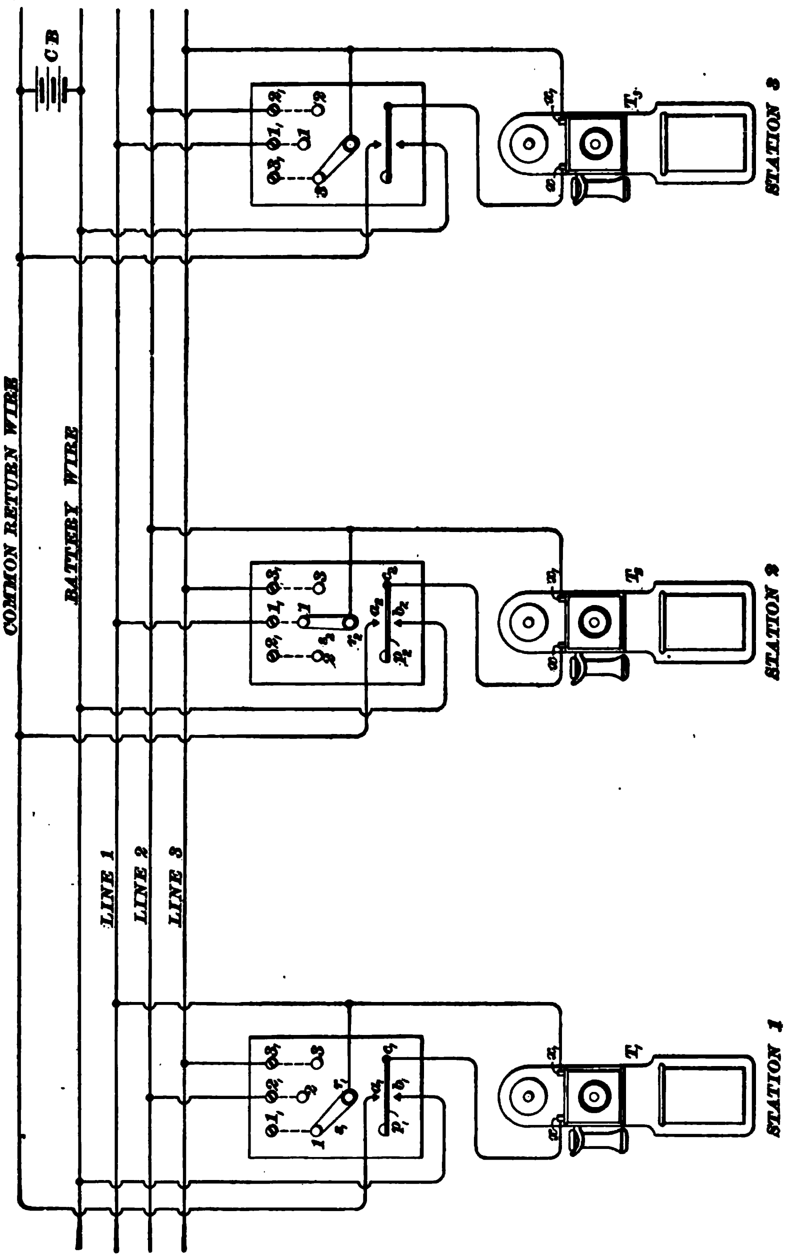

C B
COMMON RETURN WIRE
BATTERY WIRE
LINE 1
LINE 2
LINE 3
STATION 1
STATION 2
STATION 3

FIG. 61.

The telephone instruments for the common-battery call system should cost at least three or four dollars less per station, and although one extra common-calling battery and one extra line will be required, it is the cheaper to install, and if the batteries are properly attended to, should give very satisfactory service. The magneto-generator and polarized-bell system will require less attention, and for that reason is more desirable.

TELEPHONY.

(PART 4.)

THEORY OF TELEPHONE-LINES.

ELECTRICAL PROPERTIES OF TELEPHONE-LINES.

1. Resistance.—The resistance of a telephone-line circuit has two components: first, the resistance of all apparatus connected in the circuit, and second, the resistance of the line-wire itself. The resistance of the line-wire may be determined from tables, which will be given later, or by direct measurements by the methods outlined in the Instruction Paper on *Electrical Measurements*. It has already been stated that a moderate amount of resistance does not in itself seriously interfere with telephone transmission, but resistance in combination with electrostatic capacity may impose a very serious obstacle, as will be pointed out later.

In many of the toll lines, and especially party lines having instruments connected in multiple, the resistance of the line-wire often seriously affects the ringing of the call-bells at distant stations, thus limiting the number of instruments that can be placed on a line, or rendering exceptionally powerful generators necessary. This difficulty is met with to the greatest extent, of course, where these toll lines are constructed of iron, as an iron wire possesses practically six times as great a resistance as a copper wire of the same size. In this connection it may be stated that no more than ten ordinary bridging instruments should ever be connected across the two sides of a line circuit, if the resistance of the line-wire itself is more than 1,000 ohms.

2. Self-Induction.—The self-induction of a telephone circuit is almost entirely concentrated in the electromagnets connected in its circuit, and its effects are therefore, so far as the line-wire is concerned, but slight, and may, when a line is properly constructed, be neglected. It has been shown, under the discussion of alternating currents, that self-induction tends to increase the apparent resistance of a circuit to alternating currents, this increase of apparent resistance being due to the electromotive force of self-induction, which tends to oppose the electromotive force impressed upon the line, and, therefore, to cut down the current flowing, in much the same way as an increase of actual ohmic resistance would do. It has been found by experiment that for metallic circuits of copper, the apparent resistance, or impedance, as it is called, is but little more than the actual resistance.

The wire ordinarily used for long-distance telephone work is of copper, having a diameter of .104 inch, equal to a No. 12 New British standard gauge, and approximately to a No. 12 Birmingham wire gauge, and a resistance of about 5.2 ohms per mile. This resistance is, of course, the actual resistance of the wire. The apparent resistance of this wire to alternating currents having a frequency of 1,500 alternations per second is only about 1.4 per cent. greater, or about 5.27 ohms. As 1,500 alternations per second correspond approximately to the pitch of the highest tones it is desired to transmit telephonically, the average apparent resistance to telephonic currents would be somewhere between 5.2 and 5.27 ohms per mile, the difference due to self-induction being so small as to be practically negligible.

3. Capacity.—The effects of a condenser bridged across a circuit carrying alternating currents has already been dealt with. It has been shown that the condenser introduces an electromotive force of its own, which is in advance of the electromotive force impressed upon the line, and which therefore tends to make the current flowing in the line lead the impressed electromotive force in phase. It also, like self-induction, has the effect of increasing the apparent resistance of the line by introducing an electromotive force which the impressed electromotive force must overcome. Condensers are only placed on telephone-lines where it is necessary that they should perform some particular function, as, for instance, in the common-battery systems already described. Condensers when so placed introduce what is called local capacity into the circuit, and this is usually so arranged as not to be deterimental to telephone transmission, and therefore need not be considered here.

4. Distributed Capacity.—Every telephone-line may be considered as one plate of a condenser. If the circuit is a grounded one, the single line-wire corresponds to one plate of the condenser, the insulation or atmosphere to the dielectric, and the earth, or surrounding conductors, to the other plate. If the circuit is metallic, one of the wires forms one plate of the condenser, the air between the two wires is the dielectric, and the other wire forms the other plate. The capacity of a line is distributed throughout its entire length, and is therefore termed distributed capacity; each element or short piece of the line-wire may be considered as forming one plate of a condenser, the other plate of which is formed by corresponding portions of surrounding conductors. The line circuit may therefore be considered as an infinite number of small condenser plates, each acting upon alternating currents flowing over the line, according to the laws already pointed out in the consideration of alternating currents.

5. The action of distributed capacity may be made more clear by considering a number of condensers bridged across a metallic circuit, as shown in Fig. 1, instead of considering each successive element of the line-wire as a portion of a separate condenser. If the electromotive force of the generator *G*, placed across the line circuit at one end, is suddenly raised, current will be sent over the line, a portion of it flowing into each condenser, the condenser plates keeping at the same potential as that point of the wire to which it is connected. Condenser *1* will receive the greatest portion of the charge because it is subjected to the highest difference of potential. Condenser *2*, owing to the resistance of the line-wires between *1* and *2*, will be subjected to a slightly smaller difference of potential, and hence will receive a slightly smaller charge, and so on throughout the entire number, the current flowing into each

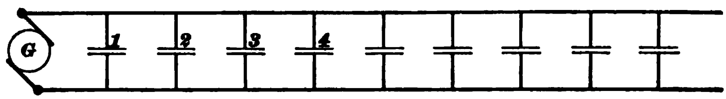


FIG. 1.

condenser, of course, detracting from the amount flowing into the more distant portions of the line. If the electromotive force continues long enough in that direction, a sufficient quantity of current will flow through the line to charge all the condenser plates to the full amount; but if the electromotive force continues only long enough to allow enough current to flow through the line to charge condenser *1*, the charge in each successive condenser being less and less, the last few condensers will receive practically no charge.

When it is stated that condenser *1* will be charged before condenser *2*, it must not be imagined that this slowness on the part of *2* in taking its charge is due to the speed at which an electric wave may travel along a conductor. This speed is practically equal to that of light, 186,000 miles per second, and on the longest line obtainable, the time necessary for an electric impulse to flow through it would be almost too small to measure. It should rather be looked at in the following light: The amount of electricity in coulombs that will flow through a conductor depends upon the number of amperes flowing and upon the length of time the current continues to flow. The charge of a condenser may be measured in coulombs, one coulomb being that amount of electricity represented by a flow of one ampere for one second. Obviously, here is a time element which is not dependent upon the actual velocity of electricity. If one ampere flows into a condenser for one-half a second, the charge assumed by the condenser during that time will be one-half a coulomb, and in one-quarter of a second will be one-quarter of a coulomb. Similarly, the amount of electrical energy that can flow through a conductor depends upon the strength of the current, the voltage, and the time of the flow.

6. If at a given instant an electromotive force in one direction is impressed upon such a line as is shown in Fig. 1, there will be a rush of current into the line-wire which will tend to charge the condensers; the potential at the terminals of condenser *1* will be greater than that at the terminals of condenser *2*, and similarly, that at *2* will be greater than that at *3*, and so on, this difference of the potential across the various condenser terminals being due to the drop caused by the ohmic resistance of the line-wire. Condenser *1* will therefore take the greater charge, condenser *2* a somewhat smaller charge, and so on through each successive condenser. If condensers *1*, *2*, *3*, and *4* have the capacity to take a certain amount of charge when subjected to the potentials mentioned, and the electromotive force impressed upon the line acts only long enough to allow that amount of current to flow from the source, and then reverse, then it is evident that condensers *1*, *2*, *3*, and *4* will each take their respective charges, and the small amount of electricity which flowed from the generator is insufficient to charge the condensers beyond. There will, therefore, be no appreciable flow of current in the line-wires beyond condenser *4*, for upon the reversal of the electromotive force, the charges of the various condensers will merely flow back to the source. It is not difficult to see, therefore, that a rapidly alternating electromotive force may be impressed upon one end of such a line without any of the current impulses ever reaching the other end, the time between the successive impulses being insufficient to allow a sufficient *quantity* of electricity to flow through the line to charge all the condenser plates. If, now, each small portion of the line-wire be considered as a condenser plate, it will be seen that the effect will be practically the same as that illustrated in Fig. 1.

7. The K. R. Law.—From the foregoing we may conclude that the length of time necessary for an impulse of current to reach the distant end of a line depends not only upon the distributed capacity of the line, but upon the resistance of the line-wire itself. It has been proven by extensive experiments in telegraphy that the length of time required for a current to reach its maximum at the distant end of the line varies directly as the product of the capacity of the line and its resistance. Mr. Preece, chief electrician of the British P. O. Department, has applied this rule to telephony in the following manner: If the product of the capacity in microfarads and the resistance in ohms of a copper circuit exceeds 15,000, telephonic transmission over that circuit is impossible. This rule he bases on the fact that for the average frequency of telephone transmission, the impulses of current would not have had time to reach the farthest end of the line, and those impulses corresponding to the lower frequencies would be so unduly distorted as to render the results unintelligible. While there seems to be little doubt but that the K. R. rule should be applicable to telephony as well as to telegraphy, there is much doubt as to the correctness of Mr. Preece's constant, 15,000.

8. In fact, it has been proven in this country time and again that good transmission may be had over lines whose K. R. product greatly exceeds 15,000, which fact has justly caused the K. R. law as applied to telephony to fall into disrepute. The fact remains, however, that the product K. R. has a direct influence upon the difficulty with which speech may be transmitted, and it is therefore well to bear in mind that in the design of telephone circuits this product should be kept as low as possible.

The electrostatic capacity of overhead copper wires, suspended at a height of about 30 feet above the ground, is approximately as follows:

TABLE 1.

No. (B. & S. Gauge.)	Capacity in Microfarads Per Mile.	
	To Earth.	Wire to Wire.
6	.0156	.00936
7	.0154	.00918
8	.0151	.00909
9	.0150	.00900
10	.0148	.00880
12	.0144	.00860
14	.0142	.00840
16	.0141	.00830

Where there are a number of grounded circuits on the same pole line, the electrostatic capacity will be about 5 per cent. higher.

9. Insulation.—The insulation of a line is the degree to which the line is insulated from the ground or from other conductors. If the resistance measured through the insulating materials from the line-wire to the ground or to other conductors is very high, the insulation is said to be good; if very low, it is said to be poor. A properly constructed aerial telephone-line should in dry weather have an insulating resistance of from 2,500 to 3,000 megohms per mile. This means that the resistance of all the leakage paths from a line-wire (not purposely grounded) to other conductors and to the ground measures from 2,500 to 3,000 megohms for one mile of wire. Of course all leakage on a telephone circuit forms a by-path through which a part of the current flows, thus reducing the amplitude of the wave which reaches the distant end of the line. Leakage in itself does not tend to destroy clearness, but only to reduce the loudness. The advantages to be obtained by very high insulation on long lines are in a measure offset by the fact that a certain amount of leakage tends to reduce the condenser action between the two sides of the line by allowing the static charges to leak across, and thus prevent, in some measure, the injurious effects of capacity upon the form of the waves. This accounts for the fact that certain telephone-lines apparently work better in wet weather than in dry, a fact which it is very puzzling to explain until viewed from this standpoint.

DISTURBANCES IN TELEPHONE-LINES.

CAUSES OF NOISES IN TELEPHONE CIRCUITS.

10. Strange noises are frequently heard in instruments connected with grounded telephone-lines of considerable length. These noises may be due to one or more of several causes. The sudden shifting of the earth's magnetic field may induce currents in the line, which will cause sounds in the receiver; earth-currents, due to differences in potential between the ground plates at the end of the line, may also pass through the telephone instruments, producing the same result; there may be leakage from other lines; a neighboring wire carrying fluctuating currents will have set up about itself a varying magnetic field of force, which field may embrace the telephone-line under consideration, and cause by its fluctuations corresponding alternating currents to flow in the telephone-line; and there may be a condenser action between the telephone-wire and the neighboring wire by which the latter may induce fluctuating charges on the former, which charges, in trying to flow to the ground, will produce currents capable of affecting the receivers.

11. Noises from Natural Phenomena.—The noises due to natural phenomena, such as changes in the earth's magnetic field, or earth-currents, are greatly increased during magnetic storms or auroral displays. It has been noticed by some that at the time of the appearance of sunspots the noises are apparently increased. These noises may be of widely different characters; sometimes they resemble the boiling or bubbling of water, sometimes the hissing of steam, and sometimes the twittering of birds. They are frequently so loud and persistent as to render conversation impossible. These noises occur on long grounded lines, and particularly on those running north and south.

12. Noises Due to Leakage.—If the insulation between a telephone-line and a neighboring line is very poor, a part of the current from the neighboring line is likely to pass by leakage to the telephone-line and produce noises in the instruments thereon. This is especially true where both the telephone-line and the other line form parts of grounded systems. Electric railways afford the greatest source of trouble in this respect, as they nearly all operate upon grounded circuits and carry very heavy currents. The potential of the earth for considerable areas is frequently raised above the normal, due to the grounding of railway circuits, and in such districts the use of grounded telephone-lines is well-nigh impossible. The current, after passing through the car to earth from the trolley-line, seeks the most direct path back to the power station, and part of it usually passes up through the ground wire at one end of a telephone-line, through the telephone instruments, and to ground at the other end, if the two ends of the line are at different potentials. These currents vary in strength according to the position of the car or cars on the line, and are of great annoyance. They can be distinguished from the currents caused by the natural phenomena by the fact that the buzz of the motors on the street-cars can be readily distinguished. The commutation of the current on the street-car motors produces fluctuations in the current, thus causing a tone in the receiver which is high or low according to whether the car is running fast or slow.

13. Electromagnetic Induction.—About every wire carrying current there exists a magnetic field or whirl, and if the strength of the current flowing in a wire is varying, this field of force will contract or expand according to whether the current strength is decreasing or increasing. If a telephone-wire lies close enough to a wire carrying such a current so as to be within its field of force, it will be cut by the magnetic lines of force as they contract or expand; and this by the well-known laws of electromagnetic induction will set up electromotive forces in the telephone-wire, which in turn will cause currents to flow through it and the receivers connected with it.

This principle is illustrated in Fig. 2, in which *A B* is the disturbing wire carrying, we will say, an alternating current, and *C D* a grounded telephone-line running parallel

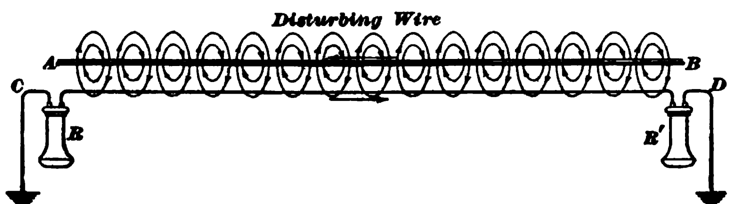


FIG. 2.

with *A B* and having two receivers *R* and *R'* connected in its circuit. If the current at any moment in the wire *A B* is flowing as indicated by the arrow and is increasing, a magnetic whirl will be set up about it, the direction of the lines of which is as indicated by the curved arrows. This whirl will be expanding while the current is increasing, and in so doing, more and more lines will cut the wire *C D*. This will induce a current in the telephone-line in the direction indicated by the arrow, which it is seen is opposite to that of the disturbing wire. When the current in the disturbing wire begins to decrease, the lines of force about it will contract, thus inducing in the telephone-line a current in the same direction as that in the disturbing wire. In general, it may be said that while the current in the disturbing wire is increasing, the induced current in the telephone-wire will be in the opposite direction; but when the current in the disturbing wire is decreasing, the induced current in the telephone-wire will be in the same direction.

14. Electrostatic Induction.—There is another and most important kind of induction between neighboring wires, due to the electrostatic action between them. This may best be explained by reference to Fig. 3, in which *A B* is the disturbing wire and *C D* a telephone-wire having two receivers *R* and *R'*, as before. If the disturbing wire is carrying alternating currents, it will receive alternate, positive, and negative charges. Assume that at a certain time the charge on a disturbing wire is positive, as indicated in Fig. 3. This positive charge will call forth two charges on

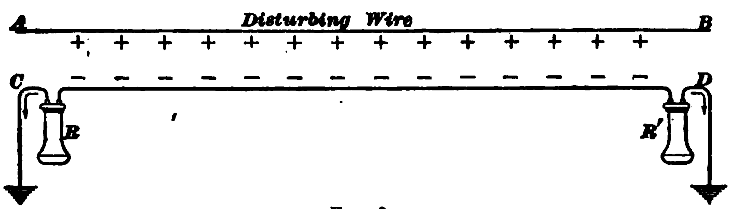


FIG. 3.

the telephone-line, one of which being negative will be held by the positive charge on the disturbing wire, while the other being positive will be repelled and will pass to ground. In order to pass to ground, it must pass through the receiving instruments at each end, and will therefore produce sounds in them. The direction of the current at this instant is indicated by the arrows in Fig. 3. If the positive charge on the disturbing wire gradually increases from zero to a maximum, the negative charge on the telephone-wire will gradually increase, thus allowing more and more of the positive charge to flow to ground. When the positive charge on the disturbing wire begins to decrease, the negative charge on the telephone-wire will also decrease, and therefore positive electricity from the ground will flow up through the receivers to neutralize it. As the charge on the disturbing wire changes from plus to minus, the bound charge on the telephone-wire will change from minus to plus, and the action just described will be reversed.

15. Where the disturbing wire is a portion of a circuit carrying current for lighting or power purposes, the induction, whether electromagnetic or electrostatic, or both, assumes the form of a hum, corresponding in pitch to the number of fluctuations per second in the current flowing in the circuit. The tone produced is not unlike that of an alternating-current transformer, and may be readily distinguished from any other line disturbances. Alternating-current circuits of course produce far greater inductive effects than direct-current circuits, but even the latter cause much trouble, owing to the fact that the commutation of the direct currents is never such as to produce a perfectly smooth current. Sometimes the disturbing wire is a telegraph-wire, and induction from this source may be unmistakably distinguished, due to the fact that the telegraph signals are repeated in the telephone receivers.

CROSS-TALK.

16. Induction may take place between two or more adjacent telephone-lines to such a great extent that a conversation carried on over one line may be heard on the others, even though the lines are entirely and perfectly insulated from each other. This phenomenon of overhearing conversation on a circuit other than that over which it is originally conducted is called **cross-talk.** It produces much confusion when one or more subscribers are talking at the same time, and its elimination was at one time the main problem involved in practical telephony.

17. Carty's Experiments on Cross-Talk.—It has been and still is believed by some that cross-talk is due entirely to electromagnetic induction. Mr. John J. Carty, however, conducted a series of experiments which proved conclusively that cross-talk is almost entirely attributable to electrostatic induction—to so great an extent, in fact, that electromagnetic induction may, upon ordinary telephone circuits, be entirely neglected. The experiments by which he demonstrated this are very interesting, and several of them will be considered.

In Fig. 4, *A B* is the disturbing wire and *C D* the wire upon which the inductive action was to be studied. These two wires were each two hundred feet long and one-eighth of an inch apart, and well insulated from each other. The line *A B* is open at one end, the other end being grounded through the secondary winding of an induction-coil. The primary winding was connected in circuit with a transmitter and a battery, and in front of the transmitter was

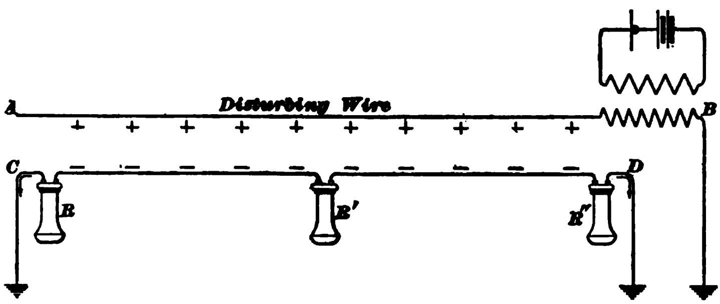


FIG. 4.

mounted a tuning-fork, which by its continuous vibration caused the transmitter to produce undulations in the primary current, which in turn impressed an alternating electromotive force upon the line-wire *A B*. Inasmuch as the wire *A B* is open at one end, the conditions are more favorable for electrostatic action than for electromagnetic, because the only current which can actually flow in the line *A B* is that which is required to charge it up to the potential of the impressed electromotive force. If at the moment considered a positive charge is formed on the disturbing wire, a negative charge will be held on the line *C D*, as already described. As the charge on *A B* changes to negative, the negative charge on *C D* is released and is replaced by a positive charge. These charges on the wire *C D* will pass to ground through the path of least resistance, that is, from the center to the ground-connection at each end of the line. This means that at any instant the current flowing in the line *C D* will be either towards or from its center point, and if a receiver *R'* is placed in the line at that point, there should be no sound in it, while the receivers *R* and *R"* will each be actuated by the currents passing through them to or from the ground. This Mr. Carty found to be the case. He also reasoned that if the currents in the line *C D* were always flowing to or from its center point, it should produce no effect upon them if the line were opened at that point. An experiment proved this supposition to be true. By grounding the point *A* of the line *A B* through a considerable resistance, he found that the same results held true, and that although a complete circuit was afforded for the alternating currents generated in the secondary coil in the line *A B*, the induction was still electrostatic. If electromagnetic induction had been present to any considerable extent, noises would have been heard in all three of the receivers, for at any instant the current would be in the same direction through all three of them. Moreover, opening the wire *C D* at its center point would preclude the flow of current through the wire from one end to the other, and therefore render electromagnetic induction impossible.

18. As another experiment, Mr. Carty arranged the circuits as shown in Fig. 5. In this, a key *K* was provided, by means of which the receiver *R* at one end of the line could be short-circuited. With this key open, the usual tones, due to the induced current, were heard in both receivers. With the key closed, it was found that the noise in each of the receivers ceased. This proved conclusively that the induction was electrostatic, for the key when closed provided a short circuit through which all the charges could pass to ground. The current would not pass through *R* because the key short-circuits it, nor through *R'* because the wire and short circuit around *R* offer a path to earth of much less resistance than that of the receiver *R'*. If the induced electromotive force had been caused by electromagnetic instead of electrostatic induction, the noises in the receiver R' would have increased, for the resistance through which the current induced in the wire A B had to flow would have been diminished, rendering the current correspondingly greater.

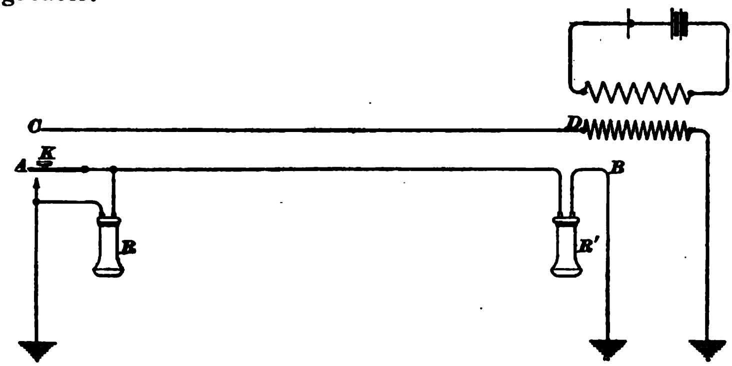


FIG. 5.

By a large number of other experiments, it was demonstrated quite conclusively that the induction or cross-talk on the experimental circuits used by Mr. Carty was unquestionably in a large degree electrostatic. Mr. A. E. Kennelly afterwards mathematically proved that the electrostatic induction on such a circuit would be about twenty times as great as the electromagnetic, which bears out well the results of Mr. Carty's experiments.

19. Overcoming Cross-Talk.—The obliteration of cross-talk was at one time the chief problem to be solved in commercial telephony, but it has been successfully and completely solved by the use of properly designed metallic circuits instead of grounded lines. When a complete metallic circuit is used, no cross-talk or other induction is developed if the disturbing wire is at equal distances from each of the telephone-wires.

This is explained by the aid of Fig. 6, where the two halves of a complete metallic circuit are shown at a and a', r and r' representing the coils of telephone instruments placed at opposite ends of the circuit, and *c d* representing a disturbing wire placed in such a position that all its points will be at the same distance from *a* that they are from *a'*. If the alternating charges are produced upon *c d*, either by a telephone or by any other source, alternating charges with opposite signs to these will be produced upon *a* and *a'*. When a negative charge is produced upon *c d*, a positive charge is produced upon the sides of the wire *a* and *a'* that are nearest to *c d*, while upon the other sides, negative charges are produced. As the metallic circuit is not grounded, this negative charge can not flow to earth, and

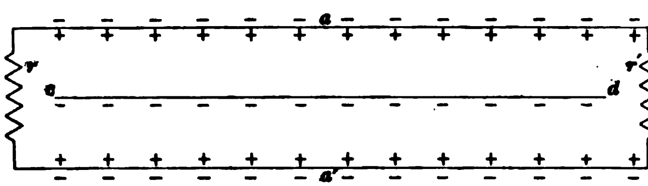


FIG. 6.

therefore flows as far as possible away from the negative charge on the wire *c d*, which is at the opposite side of the wire *a* and *a'*, as shown. As the charge on *c d* reaches zero, a current will flow *across* each wire, but not lengthwise, for the potential is exactly balanced on each side of the wire *a* and *a'*. The charges of opposite sign simply come together and neutralize each other across the wires. There is no tendency for the free negative charge on *a* to flow away, as in the case of the grounded wire, because there is an equal free negative charge everywhere on the circuit. If, however, the wire *c d* is nearer to *a* than to *a'*, the free negative charge on *a* will be greater than that on *a'*, and some current would flow. In this case, the line would be said to be out of balance, and some cross-talk or induction would take place. The arrangement of circuits shown in Fig. 6 is an ideal one, which can seldom be attained in practice.

20. Fig. 7 shows a case where both wires of a telephone circuit are on the same side of the disturbing wire *C D*.

The wire $A B$ is quite close to $C D$, but the wire $E F$ is so much farther off that it is practically beyond the variable field produced by $C D$. When $C D$ is charged negatively, $A B$ will be charged positively, the free negative charge in the telephone circuit flowing as far off as it can, that is, into the wire $E F$. In doing so, all the charges on the wire $A B$ to the right and left of the receiver R_1, which is at the middle of the resistance of the wire $A B$, will flow through the end receivers R_2 and R, respectively, to the receiver R_3; that is, the charge divides at R_1 and flows to the right and to the left from that point.

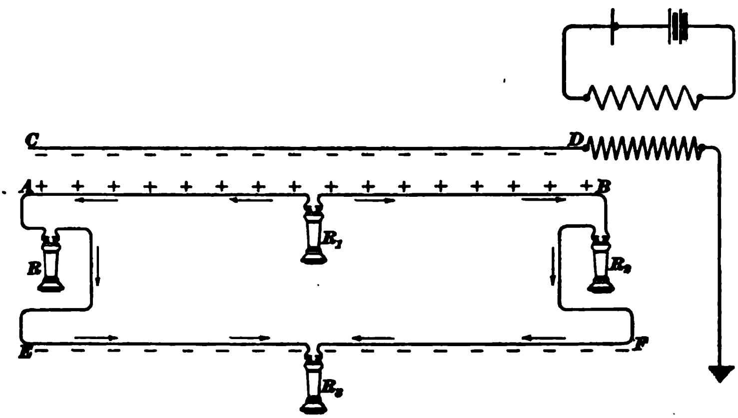


FIG. 7.

When the charge on $C D$ becomes zero, this action is reversed and the positive charge on $A B$ divides at R_1, flowing back through the two end receivers R and R_2 to meet and neutralize the negative charge on $E F$, as shown by the arrows. Thus, no charge in either case flows through the receivers R_1 and R_3, but half of the total charge in both cases does flow through each of the end receivers R and R_2. Consequently sound is produced in both R and R_2, but none in R_1 and R_3.

21. If only four wires were to be considered, those forming the sides of two separate metallic circuits, the arrangement to effect a perfect neutralization between the two circuits would be that shown in Fig. 8. In this, *a* and *a'* are the cross-sections of the wire of one circuit and *b* and *b'* those of the other. This arrangement could be readily accomplished if two circuits only were to be used, but would be unavailable for more than two, and therefore it is seldom if ever used. The method of transposition, the theory of which is illustrated in succeeding figures, is extensively used in this country, and has given the best of satisfaction on the longest lines in the world.

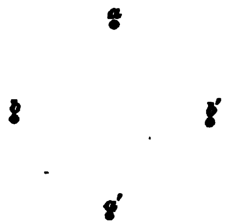


FIG. 8.

TRANSPOSITIONS.

22. Theory of Transposition.—In Fig. 9, the disturbing wire *c d* is located at one side of the metallic circuit *a a'*. The resistances *r* and *r'* at each end of the metallic

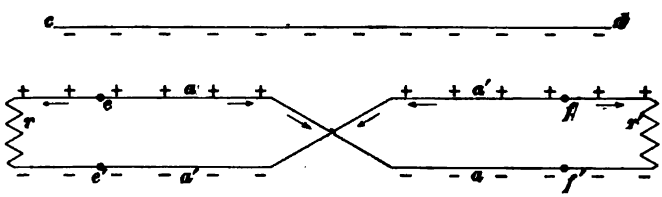


FIG. 9.

circuit represent the coils of the subscribers' instruments. It is obvious that if the two sides of the metallic circuit did not change places at the center point on the line, there would be chance for both electromagnetic and electrostatic induction, because the side of the metallic circuit nearer to the disturbing wire would be subject to greater inductive action than the side farthest away. By making a central transposition, however, the liability to cross-talk is greatly lessened. It will be seen that so far as electromagnetic induction is concerned, it is entirely eliminated, for the average distance of wire *a* from the disturbing wire is the same as the average distance of the wire *a'* from the disturbing wire.

23. When we investigate the matter with regard to the electrostatic induction, however, we find that the transposition, while it will greatly reduce the sounds in the receivers, will not completely eliminate them. When *c d* receives a negative charge, as in the figure, a positive charge is induced upon the nearer portions of *a* and *a'*, while a negative charge is repelled to the more remote portions of the same wires. As the negative charge on the wire *c d* reaches zero, currents flow from the nearer portions of *a* and *a'* to the more remote portions, and two paths are afforded to the currents thus flowing from each section of the wire. Thus, the positive charge on the left-hand portion of the wire *a* will divide, part flowing through the receiver coil *r* and part through the cross or transposition wire, in order to reach the sides of the metallic circuit which are farthest away from the disturbing wire. If the resistance through the transposition wire was the same as that through the receiver, a neutral point *e* would be found in the center of the left-hand portion of the wire *a*, from which, or towards which, all induced currents would flow. As it is, however, the resistance through the receiver *r* is much higher than that through the transposition wire, and therefore most of the current is forced through the latter path, thus moving the neutral point *e* towards the end of the line. Four neutral points *e*, *e'* and *f*, *f'* may be found on the line, as shown, and there would be no sounds in the receivers if connected in the circuits at these points. On a line of considerable length, one transposition is not enough to give complete immunity from cross-talk, because the resistance from the neutral point through the transposition is sufficient to force a considerable portion of the induced charge through the receivers at the ends. It is therefore customary to make transpositions about once every quarter or every half mile, on very long lines, and this is amply sufficient to give complete freedom from disturbing noises, even on the longest lines in use.

24. Scheme of Transpositions.—Where many wires are used, the transpositions must be carefully planned. When two circuits only are considered, transpositions in one of them only will serve to prevent cross-talk between them, although, of course, it will not serve to prevent outside disturbances from affecting the circuit which is not

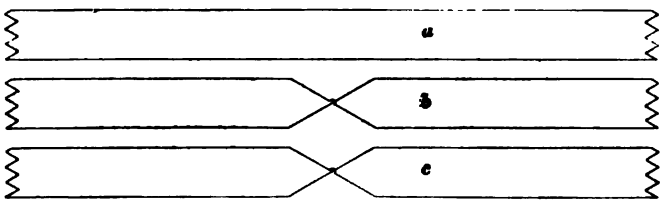


FIG. 10.

transposed. If more than two circuits are used, it will not be sufficient to transpose them all in the same manner; neither will it do to leave one of them untransposed and to transpose the others in the same manner. Thus, in Fig. 10, the circuit *a* is not transposed at all, while the circuits *b* and *c* are each transposed at their center point. If the line is a

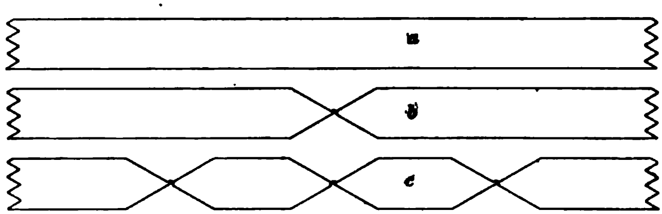


FIG. 11.

short one, there will be no appreciable cross-talk between *a* and *b*, as we have seen in connection with Fig. 9; for the same reason there will be no cross-talk between *a* and *c*; but between *b* and *c* there will be cross-talk, as the average distances of the two wires of *c* from either wire of *b* are not equal to each other. In fact, the circuits *b* and *c* bear almost the same relation to each other as if they were not transposed at all. To overcome this difficulty, twice as many transpositions must be made in the third circuit as there are in the second, as shown in Fig. 11.

25. In Fig. 12 is shown the scheme of transposition on the New York-Chicago line, the poles on which transposition are made being 1,300 feet apart. The same scheme of transposition is used on every other set of cross-arms; thus,

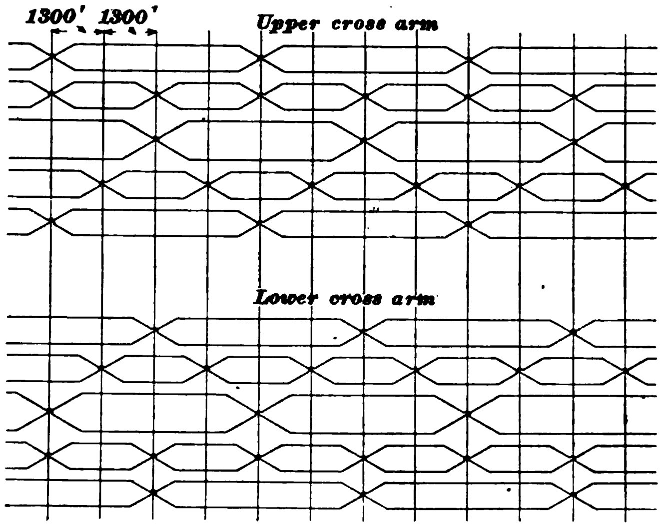


FIG. 12.

the cross-arms at the top of the poles will be arranged as shown in the upper part of Fig. 12; the next set will be arranged as shown in the lower portion of that figure; the third will be like the first, and the fourth like the second, and so on throughout the entire number of sets of cross-arms. The method of making transpositions now generally adopted is that shown in Fig. 13. The cross-over wires should either be insulated or else so bent as to avoid the possibility of crosses, the latter plan being the more common. When transpositions are made in this manner, an insulator with two grooves around it must be used. A two-grooved insulator used by the American Telephone and Telegraph

Company and local Bell Companies for making transpositions is shown in Fig. 51 (*d*). It is made in two separate

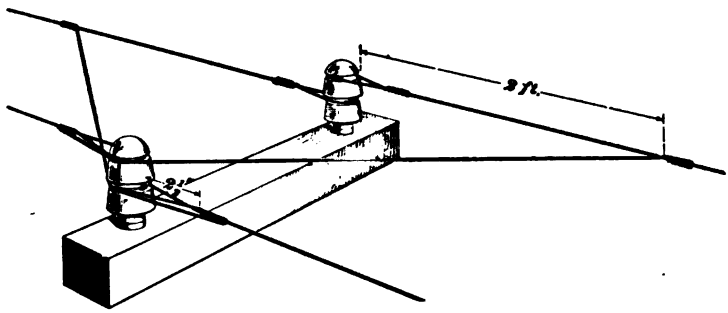


FIG. 13.

pieces, each having a groove around it. The pin screws through the lower one into the upper one. This is known as the Hibbard transposition insulator. Transpositions may also be made by the use of two cross-arms, one on each side

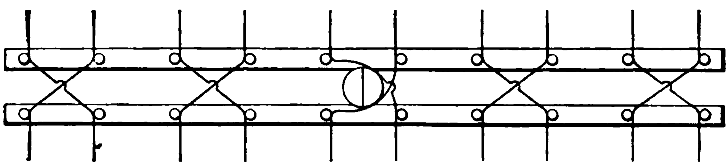


FIG. 14.

of the pole, and the ordinary single-groove pony insulators. This method, shown in Fig. 14, is inferior to the preceding. In either case the line-wire should only be looped and ***not wound even once*** around the insulator.

THE COMMON-RETURN SYSTEM.

26. In discussing telephone exchanges, the common-return system was briefly described. The common return is often called the McCluer system. By completing the circuit of each line through a heavy common-return wire instead of through the ground, as in the case of grounded systems, all trouble from earth-currents and from leakage from electric-railroad lines and other grounded circuits is eliminated if the work is properly done. With the common-return system, an exact inductive balance between the common-return wire and the various line-wires can not be obtained in practice, for it is obvious that the common-return wire can not be so spaced with regard to all the other wires as to render an equal inductive influence upon it and upon all the other wires. However, this condition can be fairly well approximated by locating the common-return wire as near the center of the other wires as is possible. For long-distance lines, however, it is impossible to secure freedom from cross-talk by means of the common-return system, and it should not therefore be used. The principal point to be considered in the construction of common-return systems is the proper size of the common-return wire.

27. In Fig. 15, *D*, *D*, *D* represent the drops at the central office, *R*, *R*, *R* the telephone apparatus at the subscribers' stations *1*, *2*, *3*, *4*, etc. *C. R.* is the common-return wire, which completes the circuits of the various line-wires L_1, L_2, L_3, etc., between the central office and the various subscribers' stations. With such an arrangement, it is evident that the return circuit for any one line is made not only from the common-return wire, but through all the other wires in multiple. To illustrate: A current set up in the apparatus at station *3* will pass over line-wire L_3 to the central office; from here the greater portion of the return current will pass through the common-return wire, but paths are also offered through the line drops and the line-wires of the other stations *1*, *2*, *4*, *5*, *6*, *7*, etc., to the common-return wire, and back to station *3*. It is evident that if the resistance of the common-return wire is not very low, it may serve to shunt enough current through the other telephone-lines to cause cross-talk. This is the principal reason why the common-return wire should be made of low resistance, and it is evident that the lower the resistance, the more perfect will be the freedom from this leakage cross-talk. Of course, when two lines—L_1 and L_7, for instance—are connected for conversation, they are disconnected from the line drops and connected together by a cord circuit, such as is shown at C, this circuit connecting the line of station *1* with the line of station *7* for conversation. Currents generated at either of these telephone stations will pass through the two line-wires and the cord circuit, the principal return being made through the common-return wire *C. R.* It will be evident, however, that a portion of the return current may be forced through the other lines in multiple with the common-return wire. Thus, a part of the current which should flow in the common-return wire from *a* to *b* might be shunted by the resistance of that portion of the common-return wire, through the instrument at station *2*, line-wire L_2, drop D of that line, common connection of the central office, drop D of line L_6, line L_6, and the instrument at station *6*, to the point *b*.

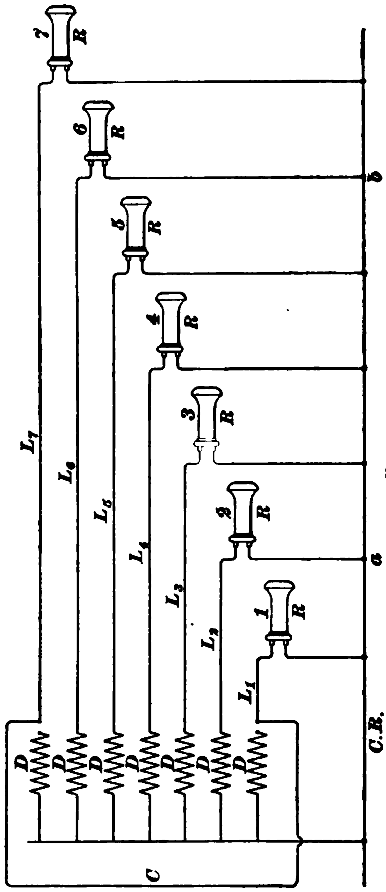


FIG. 15.

28. Size of Common Return.—No general rule can be laid down for the determination of the size of the common-return wire, but where the line-wires are of copper—say No. 12 or No. 14—a No. 6 common-return wire will usually prove large enough, although where a branch of the common-return wire serves a large number of subscribers and extends to a considerable distance from the central office, a No. 4 would be found to give better results.

CONNECTION OF GROUNDED TO METALLIC-CIRCUIT LINES.

29. It is frequently desirable, for several different reasons, to connect grounded to metallic-circuit lines. This

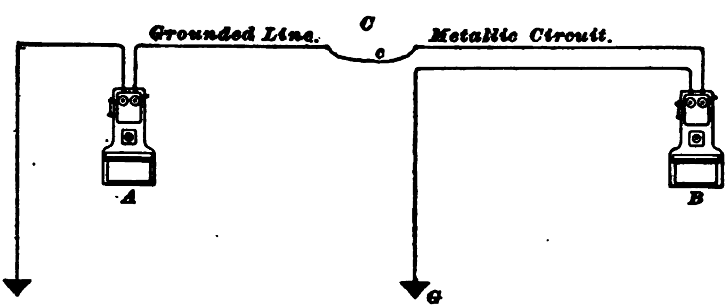


FIG. 16.

may be done by connecting them as shown in Fig. 16, where *C* is the central office, to which the two lines lead from station *A* and station *B*. *c* is a single-cord circuit connecting one side of the metallic-circuit line to the grounded line; the other side of the metallic-circuit line is connected to ground at *G*. A complete circuit now exists from the ground at station *A*, through the cord circuit *c*, one side of metallic-circuit line, to station *B*, back to the other side of the metallic-circuit line, to ground at *G*, and thence to the ground at station *A*. A complete talking circuit is thus afforded, but this method of connection should not be used except where it is impossible to make the connection otherwise. The fact that one side of the metallic circuit is connected directly with the ground completely destroys the balance of the metallic-circuit line, and thus renders it susceptible to all sorts of inductive noises from outside sources.

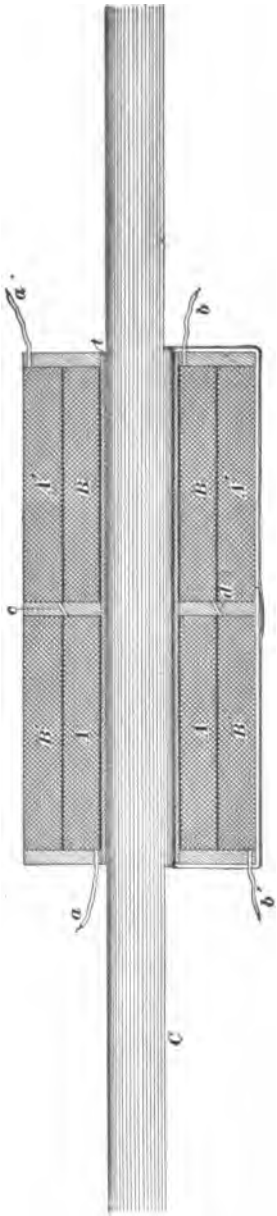


FIG. 17.

Inasmuch as the metallic-circuit lines are usually long and the grounded lines local, practically all the desirable effects obtained by the metallic-circuit line are lost by this method of connection.

30. Repeating Coils.—The proper way to connect a metallic circuit to a grounded line is by the use of a repeating coil. Repeating coils are merely induction-coils of a special type. It is customary in this country to make the primary and secondary windings of equal resistance and number of turns, the resistance of each winding being in the neighborhood of 200 ohms. The method of constructing repeating coils is shown in Figs. 17 and 18, the former figure being a sectional view of the coil in an incompleted state, and the latter a view of the coil as finished. *C* is a core composed of small, annealed iron wires, held together by being slipped into a fiber tube *t*. Upon this tube are fastened three washers, also of fiber, forming a spool upon which the windings are placed. In order to make equal the effect of the two windings upon the core and upon each other, one-half of each is placed on each end of the spool; thus, one-half of the winding *A A'* is wrapped on the left-hand end of the spool, as shown; then the first half of the winding *B B'* is placed on the right-hand end of the spool in the same manner. The second half of the winding *A A'* is then wound on top of the first half of the winding *B'*, as shown at *A'*, the different portions *A* and *A'* being connected through the dividing washer of the spool, as shown at the point *c*. In a similar manner, the second half of the winding *B B'* is wound on over the first half of the winding *A*, it being connected to the portion *B* through the dividing washer of the spool at the point *d*. The terminals of the winding *A A'* are brought out at points *a*, *a'*, while the terminals of the winding *B B'* are similarly brought out at the points *b*, *b'*. After the winding is in place and properly covered with

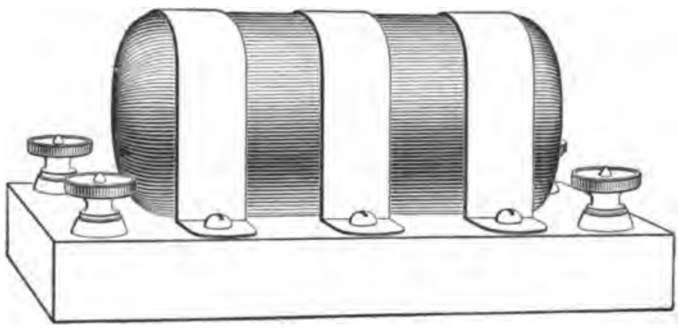


FIG. 18.

paper to prevent short circuits, the ends of the wires forming the core *C* are bent around the entire coil, as shown in the lower portion of the figure, so that the windings are entirely enclosed by the wires of the core. It will be seen that this construction makes the magnetic circuit for the lines of force set up by the coils complete, thus making the transformation from the primary to the secondary more efficient. One of these coils in its finished state is shown in Fig. 18, it being strapped to a base block by straps of brass, as shown. The terminals of the two windings are brought out to binding-posts arranged in convenient manner on the base.

31. The method of using the coil is illustrated in Fig. 19, in which a metallic-circuit telephone-line is connected through the repeating coil with a grounded line. The two terminals of the metallic circuit are connected, respectively, to two binding-posts forming the terminals of one winding of the repeating coil. One terminal of the grounded line is connected to one terminal of the other winding, while the remaining terminal is connected to ground, as shown. When the telephone connected with the metallic circuit is transmitting, the winding of the repeating coil with which

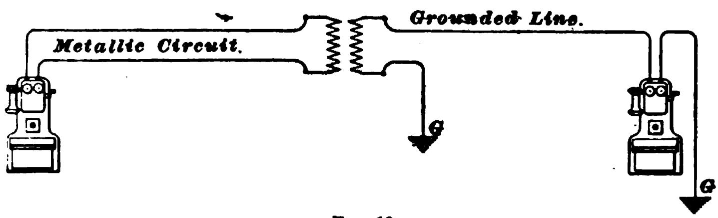


FIG. 19.

the metallic circuit is connected acts as a primary, in exactly the same manner as the primary of an ordinary induction-coil. It induces currents in the winding connected with the grounded line, which currents flow over the grounded circuit and affect the telephone receiver of its instrument in the ordinary way. When the grounded telephone is transmitting, the operation is exactly reversed, the winding connected with the grounded line serving as a primary and that connected with the metallic circuit as a secondary.

32. Advantage of Repeating Coils.—The great advantage of this method of connecting grounded to metallic-circuit lines over that shown in Fig. 16 is that the metallic circuit is kept entirely free from grounded lines. Its balance is in no wise destroyed, and the induction from outside sources is only that which would ordinarily appear upon the grounded line. There is an opinion among many telephone men that a repeating coil may be used in some mysterious manner to remove cross-talk, and, in fact, all kinds of induction, from telephone-lines. This is a fallacy. If a line is subject to induction, the repeating coil will transmit this induction through it with as great an efficiency as it will transmit the voice currents. The proper way of getting rid of induction on lines is to properly construct the lines, as has already been pointed out. The repeating coil serves merely as a means for connecting dissimilar circuits without introducing new troubles upon them.

LINE CONSTRUCTION.

THE POLE LINE.

SELECTION OF ROUTE.

33. The first important consideration in the erection of a pole line is the selection of the route. After the general route has been determined, right of way must be secured, and this is a matter involving as much business tact as engineering ability. If city lines are being constructed, it is well to mark upon a large map of the city the location of the various subscribers, and after dividing them in groups, to determine the center of distribution for each group, and to connect each such center with the central office by the most direct route available. If cross-country lines are being constructed, the most direct route is usually the most desirable, although, of course, the selection of the route must always be governed by the considerations arising in securing the right of way, by the configuration of the country, and by the nature of the soil.

34. If a line is to be built along a country road, a reliable map of the country, showing the various turns in this road, should be obtained if possible, and if not, one should be constructed by the best means available. A fairly accurate survey may be made by counting the revolutions of a wagon-wheel driven over the road, or, better, by means of a reliable cyclometer on a bicycle. Notes should be taken at every bend in the road, and, in fact, every other landmark, as to the distance passed over and as to the direction of the road, its grade, soil, etc.

POLES.

35. Selection of Poles.—The poles used to the greatest extent in this country are of the following kinds of wood: white cedar, Norway pine, chestnut, and cypress. The average lives of these under average conditions are placed by good authority at the following values:

Norway pine	6 years.
Chestnut..................	15 years.
Cypress....................	12 years.
White cedar...............	10 years.

Cedar is undoubtedly used to the greatest extent for telephone purposes, and is, all things considered, the most satisfactory timber. Considering their strength, they are light in weight, and by some authorities these poles are considered the most durable when set in the ground of any American wood suitable for pole purposes.

Chestnut is a tough and strong wood, and for that reason is often used at street corners and bends, while other poles are strong enough for the rest of the line. Chestnut poles are apt to be badly bent, and hence are not quite so good for nice pole lines in a city, although often used for such lines.

Slow-growth timber, i. e., timber which grows on barren soil, is found to be the best for poles. The selection of poles, however, must be governed to a large extent by the facility with which the various kinds may be procured in the particular locality under consideration. The poles should be well seasoned, straight, free from serious knots or cracks, and sound throughout.

36. Sizes of Poles.—The best telephone-lines in this country use no poles having tops less than 22 inches in circumference. If the poles taper at the usual rate, the specification that a pole shall have a top 22 inches in circumference, or approximately 7 inches in diameter, is usually sufficient, for the diameter at the butt will then be approximately correct, no matter what the length of the pole may be. As the taper of poles varies considerably, however, it is well in ordering poles to make the specifications conform to Table 2, taking one measurement at the top and one at a distance of 6 feet from the butt.

TABLE 2.

SIZES OF POLES.

Length of Pole in Feet.	Circumference at Top in Inches.	Circumference 6 ft. from Butt in Inches.	Depth of Pole Set in Ground in Feet.
30	22	33	5½
35	22	35	5½
40	22	37	6
45	22	41	6½
50	22	44	7
55	22	48	7
60	22	52	8
65	22	56	8

For white-cedar and Norway-pine poles, the weight in pounds and the number of poles to a carload are approximately as given in the table on the following page. Chestnut poles will be about fifty per cent. heavier than the cedar. Poles 35 feet and over must be loaded upon two cars.

37. Where a pole line is to carry but few wires, it is unnecessary to make the poles as heavy as those specified in the table, and in many cases, poles with a 5-inch top will answer every purpose. In determining the height of poles, several considerations must be borne in mind. The number of wires to be carried, and therefore the number of cross-arms, determines to some extent the general height of the pole to be used. A general rule to be followed in making

ROUND CEDAR POLES.

Length in Feet.	Diameter of Top in Inches.	Weight in Pounds.	No. to Carload.
25	5	200	120
25	6	275	110
30	6	325	100
30	7	450	80
35	6	500	120
35	7	600	110
40	6	700	100
40	7	800	90
45	6	950	82
45	7	1,100	60
50	6	1,250	40
50	7	1,450	25
55	6	1,500	30
55	7	1,800	25

NORWAY-PINE POLES.

Length in Feet.	Diameter of Top in Inches.	Weight in Pounds.	No. to Carload.
40	7	1,100	90
45	7	1,200	80
50	7	1,350	72
55	7	1,500	65
60	7	1,700	55
65	7	2,000	45
70	7	2,400	50
75	7	2,800	45
80	7	3,400	35
85	7	3,800	30

this determination is to specify that at no point shall the lower cross-arm be at a smaller distance than 20 feet from the ground. Where this rule is followed, the number of cross-arms on a pole, the distance between them, and the depth of the pole hole make the determination of the pole length an easy matter. The length of the pole must, however, be varied according to the lay of the land, as will be shown later, in order that the line of the pole tops may be as evenly graded as possible. Again, obstructions, such as the branches of trees, other wires, and buildings, must be avoided, and it is a good rule, wherever possible, to have the telephone-line go over rather than under all such obstructions.

38. Treatment of Poles. — Many attempts have been made to increase the life of poles by such processes as creosoting and vulcanizing, and some of these processes are used to a considerable extent in foreign countries. In this country, these processes are coming somewhat into commercial use, but, as a rule, the poles are set without any preparation whatever against the action of the elements. The poles should be cut at least a year before using, to give them time to dry and season, and they should be peeled, preferably before seasoning and while the sap is down, and all knots should be smoothly trimmed at the same time. The bark should be stripped off as soon as the tree is cut, to get rid of the insects under it, and also because the bark retains more moisture than the wood, and thus tends to hasten the rotting of the sound wood. In order to prevent to as great an extent as possible the action of the weather at a point just at the surface of the ground, the poles are sometimes coated with pitch for a distance of 6 or 7 feet from the butt, according to the depth to which it is to be set in the ground. The point on the pole at the surface of the ground is termed the wind-and water line, and at this point poles usually, if not specially treated, first begin to rot, this action being due to the fact that the combined effects of the air and moisture are greatest at that point.

39. Spacing of Poles.—Practice varies as to the spacing of poles in telephone-lines. Of course, the number and sizes of the wires to be carried is the most important consideration in determining this point, but the climatic conditions, especially with regard to heavy wind and sleet storms, should also be considered. In general, it may be said that the best lines carrying a moderate number of wires use 40 poles to the mile, while for exceptionally heavy lines, the use of 52 poles to the mile, or one pole every hundred feet, is not uncommon practice. On the other hand, many pole lines carrying but few wires use only 25, and sometimes as low as 20, poles to the mile. As a general rule, which it is well to follow, in nearly all cases 35 or 40 poles to the mile should be used. For city work, the poles should be set on an average not farther apart than 125 feet, and they should be painted and provided with steps.

LAYING OUT POLE LINE.

40. Having selected the general route, the location of each pole should be determined and marked with a stake before the hauling of poles or other material is begun. In doing this, a 150-foot steel tape line is desirable. Several marking flags of white cloth, about 2 feet square and mounted on 10-foot poles, sharpened at one end, together with a light ax, will be the only other tools necessary in locating the poles. Assuming that the line to be constructed is to follow the southern side of the roadway shown in Fig. 20, that the average number of poles to the mile is to be 40, and that the maximum allowable distance between the poles under ordinary circumstances is 140 feet, the average being 132, the work should proceed as follows: Beginning at position *1*, drive a stake into the ground at a proper distance from the road center or fence, and measure off a convenient number of 132-foot lengths. In this case, it may be convenient to measure in this way as far as the first bend in the road at *A*. Make a mark on the ground at each 132 feet, and leave a stake at each mark.

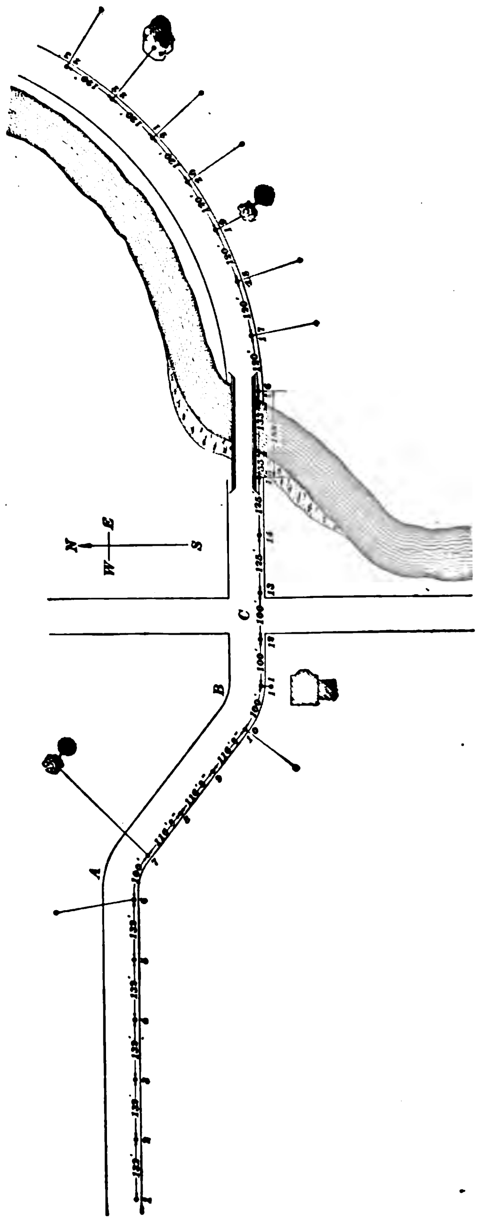


Fig. 20.

Now have a helper place his flag at the position for the sixth pole, due care being taken that the distance from the center line of the road or from the adjacent fences is correct. As the section of road between positions *1* and *6* is straight, the intermediate stakes may be located directly in line with *1* and *6*, a sight being taken by the eye between a flagpole held on stake *1* and the flag at stake *6*. The helper locates the proper position for each stake by holding a flag in an approximate position and moving it to the right or left, according to signs given by the party sighting at stake *1*. After the proper location of stakes from *1* to *6*, all should be driven home and numbered, either by an ordinary tag, or, better, by marking with soft lead directly upon the stake. Convenient stakes for this purpose are made of yellow pine 20 inches in length and about 1¾ inches square. At *A* a sharp bend occurs in the road, and as a side strain will be caused upon the poles at that point, it is well to locate the two poles which are to stand this strain closer together. Stake *7* will therefore be placed at a distance of, say, 100 feet from stake *6*, and located at the proper distance from the road center. Before locating the next poles, the conditions at the bend *B* in the road and at the cross-road *C* should be investigated. It will be better, as before, to make the turn at *B* on two poles placed at about 100 feet apart. Therefore these two poles at *B* are located at proper distances from the road center, and in such manner that the distance between them will be nearly bisected by the angle in the road. The distance between the western pole at *B* and pole *7* is then measured and found to be 350 feet. This will make three spans 116⅔ feet long, and as this short section of the road is straight, the two intermediate stakes *8* and *9* are located in a straight line between poles *7* and *10* by the method already indicated. 132 feet from pole *11*, which is already located, would bring pole *12* into the center of the cross-road, while the span would be longer than 140 feet if pole *12* were located at the other side of this road. Therefore it will be necessary to make another short span, and pole *12* is located 100 feet from pole *11*, as shown. The next span of 132 feet would more than clear the roadway, but inasmuch as this is a cross-road, where it is particularly desired not to have broken wires, it will probably be better to make another short span across it of, say, 100 feet. From pole *11* to the river is a straight stretch, and from pole *13*, located just on the east side of the cross-road, the distance is 250 feet.

41. The poles on the banks of the river must be located with great care, due consideration being taken of the nature of the soil, the elevation of the banks, and the length of the span across the river. The distance from water edge to water edge of this river at this point is found to be 133 feet, but the soil on the west bank is so marshy for a distance of 50 feet as to afford no proper footing for a pole. The nearest firm ground on the west bank is at a point 55 feet from the water edge, just near the entrance of the iron bridge spanning the river. A pole should therefore be located at that point. On the opposite side of the river a solid rock rises abruptly from the water edge back for about 50 feet. This rock will make an excellent foothold for a pole, although, of course, powder must be resorted to in blasting the hole. The pole is located, therefore, as close to the river as possible, its location being marked by a cross-mark scratched upon the rock.

Upon measuring this span across the river, it is found that the distance between the poles is 188 feet, but as it is impracticable to locate them closer together, and as the bridge may afford no facilities upon which to mount a bracket, this span must be tolerated, great care being taken, of course, in properly securing it in the future operations. From the pole on the western bank of the river to pole *13* is found to be 250 feet, thus giving two 125-foot spans. From pole *11* to pole *16* is a straight line, and therefore the intermediate poles *12*, *13*, *14*, and *15* should be accurately located in line by sighting between the flags. After crossing the river, the roadway follows the river-bank for about a quarter of a mile in an even curve northward. It should be made a rule to place the poles somewhat closer together than the average on curves, but inasmuch as this curve is a gradual one, the normal length of span need not be reduced to a great extent. A distance of 120 feet between poles will therefore be decided upon for all the spans on this curve. The succeeding poles are therefore located 120 feet apart, and each at a proper distance from the road center. If the roadway was not a smooth curve, the poles on all straight portions should be alined as described, while those on the curves should be made to follow as nearly smooth curves as possible.

The stakes should be located on a map, such as shown, and the distances between them clearly marked either on the map or upon a separate table.

42. Locating Guy Stubs.—All poles upon which turns are made should be securely guyed in such manner as to entirely counteract the side strain on the line-wires. In locating the poles, it is also well to mark the position of the guy stubs or anchors to which the guy wires are to be attached. In doing this, much judgment must be exercised, and right-of-way privileges must also be consulted. It is frequently a much more difficult matter to obtain permission to anchor a guy wire on a piece of property than it is to locate a pole. The anchor for the guy wire should always be located so that the direction of the guy wire will bisect the angle made by the line-wires on that pole. It is evident that poles *6*, *7*, *10*, *11*, *17*, *18*, *19*, *20*, *21*, *22*, and *23* will need to be guyed, and note is made of this fact in locating the poles, and the guy stubs located by stakes in the same manner as the poles. The stubs should also be marked on the map. Poles *6*, *10*, *17*, *18*, *20*, *21*, and *23* will in Fig. 20 be guyed to stubs placed at positions located. Poles *7* and *19* will be guyed to tree trunks, as indicated in the map, while the guy wire of pole *22* will be anchored in the convenient ledge of a rock, the ground at that point being too stony to erect a guy stub without undue trouble. At pole *11*, which is opposite a residence, no permission could be secured from the owner to plant a guy stub in his front yard, and therefore an anchor is provided, as will be described later, close to the base of the pole.

43. Grading Line of Pole Tops.—Where the line passes through a level country, all the poles may be of the same length, except where changes are necessarily made in order to avoid obstructions. In a hilly country, however, it is important that the line of the pole tops should be as nearly on a level as possible, and this necessitates the putting of long poles on the low ground and short poles on the high. That this is important may be seen by comparing Figs. 21 and 22. In Fig. 21, where all the poles are of the same length, a very heavy strain would be brought upon poles *2* and *4*, and pole *3* would probably have an upward instead of a downward pull upon it by the wires, thus serving to increase the strain upon the poles *2* and *4* rather than diminishing it. Cases have been known where, owing to

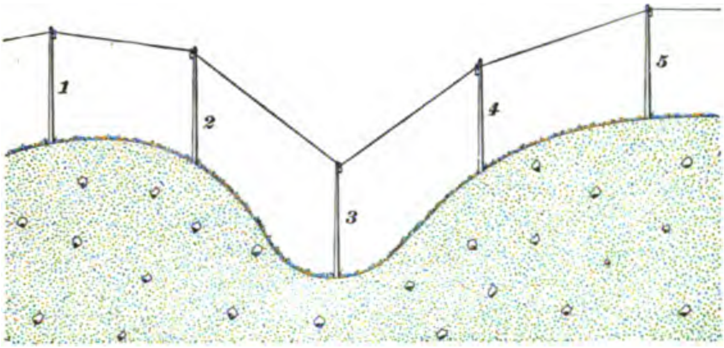


FIG. 21.

such faulty construction as that indicated in Fig. 21, the insulators were pulled off, and even the pole in the hollow was lifted entirely out of the ground and hung suspended

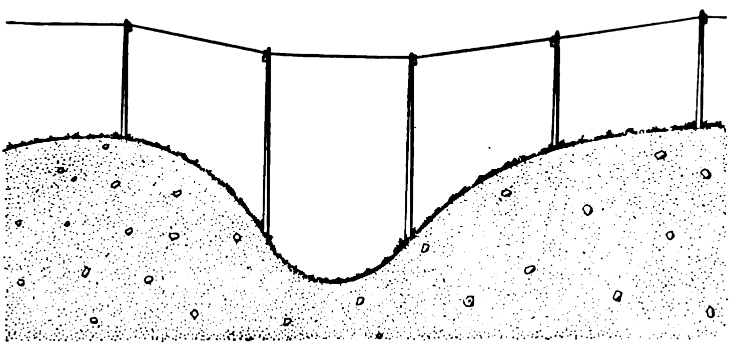


FIG. 22.

by the line-wires. At any rate, a pole in such a position is much more likely to do harm than good.

44. In Fig. 22, the unevenness in the profile of the line is corrected to some extent by the use of poles of varying lengths, and by a different arrangement of the poles with respect to the configuration of the ground. As will be noted, two poles are used in the ravine, one on each side, instead of one in the bottom of the ravine, as in Fig. 21. Moreover, these poles are made longer and the poles on the hilltops shorter, thus maintaining a very fair grading of the pole tops without subjecting any of the poles to undue strain.

45. In a country having only slight undulations, the length of pole put in any particular position can usually be determined by a mere inspection with the eye. If the country is very undulating, it is a good plan, and one that should be carried out if possible, to make a profile map of the entire pole line with a surveyor's level and leveling rod. For this purpose the level should be set up between stakes *1* and *2*, and a sight taken at the leveling rod while held above stake *1* by the helper. The helper should then go to stake *2*, and a sight should be taken on the rod when held above it, the level remaining at the same point. The readings so obtained are called back and front sights, respectively, and the difference between them indicates the difference in level between stake *1* and stake *2*. In the same manner, the difference in level between stake *2* and stake *3* may be obtained. After the levels of all the stakes have been determined, an accurate profile of the country over which the line passes may be mapped out upon a piece of section paper, and after this is done, the profile of the line of pole tops may be drawn in such manner as to remove all undue vertical bends, this being accomplished, of course, by varying the length of poles as already described. After this, the lengths of poles may be scaled and a table made so that the proper length of pole may be hauled to each stake.

This method is not usually followed, and is unnecessary if the country is gently undulating; but in a very hilly country, a careful following of this plan will result not only in a better line, but will actually save labor and expense.

ERECTING THE POLE LINE.

46. Distribution of Poles.—After these preliminaries are arranged, the poles may be distributed by any means available. They should be laid with their butts near the stake and with their small ends pointing up hill if there is a grade at that point. By following the latter point, much labor on the part of the raising gang will be saved. Another point which should be observed in the distribution of poles is that the heavier poles should be placed on the corners and on all points where a heavy strain is likely to occur.

47. Gaining and Trimming.—When the pole is received, its butt should be approximately square. If this is not the case, it should be made so before setting. Before raising the pole, the gains for the cross-arms should be cut and the small end of the pole made wedge-shaped by chamfering the top to an angle of 45°, the direction of the wedge being in a line parallel with the wires. It is customary to place the center of the upper gain 8 or 10 inches from the apex of the roof, and to make the distance between the centers of the cross-arms 20 to 24 inches. A pole top prepared in this manner is shown in Fig. 23. The roof should be painted with two or three coats of best white lead, as should also all the gains, before the cross-arms are fastened in place. This treatment prevents the entrance of moisture into the grain of the wood and greatly prolongs the life of the pole.

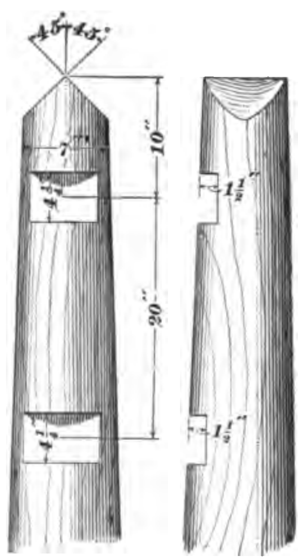


FIG. 23.

48. Cross-Arms.—The cross-arms should be made of well-seasoned straight-grained Norway pine, yellow pine, or creosoted white pine. Their size and length depend on the load they are to carry. Two regular sizes, however, are made, one termed the standard cross-arm and the other the telephone cross-arm. The standard cross-arm is used for all heavy work, and in constructing a line that is expected to last well, this size of arm should be used. The

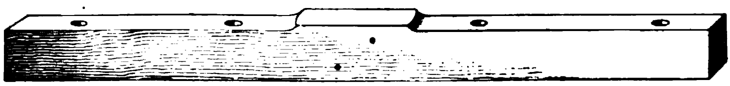


FIG. 24.

standard cross-arm is $3\frac{1}{4} \times 4\frac{1}{4}$ inches and varies in length from 3 to 10 feet. They are usually bored for $1\frac{1}{2}$-inch pins and provided with holes for two $\frac{1}{2}$-inch bolts, as shown in Fig. 24. The number of pins and the spacing of the pins for the various lengths of standard cross-arms are given in Table 3.

TABLE 3.

STANDARD CROSS-ARMS.

Length.	No. Pins.	Spacings.		
		End.	Center.	Sides.
3 ft.	2	4 in.	28 in.	
4 "	4	4 "	16 "	12 in.
5 "	4	4 "	18 "	17 "
6 "	4	4 "	22 "	21 "
6 "	6	4 "	16 "	12 "
8 "	6	4 "	18 "	$17\frac{1}{2}$ "
8 "	8	4 "	16 "	12 "
10 "	8	4 "	$17\frac{1}{2}$ "	$15\frac{3}{4}$ "
10 "	10	4 "	16 "	12 "

49. The telephone cross-arms are lighter, being made from $2\frac{3}{4} \times 3\frac{3}{4}''$ stuff, sometimes $3 \times 4\frac{1}{4}''$, and bored for

1¼-inch pins and provided with two ½-inch bolt holes. For light lines these arms give excellent satisfaction, but are not, of course, as durable as the heavier arms. All cross-arms should be painted with two coats of good oil paint before leaving the factory. A good paint for this purpose

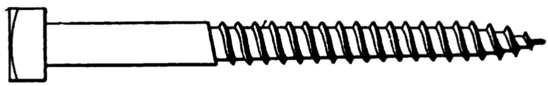


FIG. 25.

consists of seven pounds of Prince's metallic paint mixed with one gallon of pure linseed oil. Cross-arms are usually fastened to the poles by two ½-inch lag-bolts (see Fig. 25) of sufficient length to pass nearly through the pole, the length used on standard constructions being usually 7 inches.

50. It has been found that the entrance of a lag-screw destroys the grain of the pole to such an extent that it is seldom possible to put on new cross-arms after the pole has been in service for several years. A more recent and much better plan, therefore, than the use of lag-screws is to secure the cross-arms to the pole by carriage-bolts, such as shown in Fig. 26, the carriage-bolt being ⅝ inch in

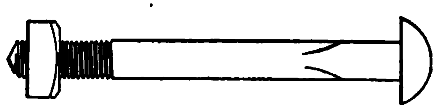


FIG. 26.

diameter and long enough to extend entirely through the pole and cross-arm. A washer not less than 2½ inches in diameter should be used under both the head and the nut of this bolt. On the telephone cross-arm, the centers of the end pins are 3 inches from the ends of the arm, the distance between the centers of the two middle pins being 16 inches, and between all others, 10 inches.

51. Cross-Arm Braces.—In order to further secure the cross-arms, what are termed cross-arm braces are used. One of these is shown in Fig. 27. These are made of galvanized iron, from 20 to 30 inches long and usually 1¼ inches wide by ¼ inch thick. The method of attaching

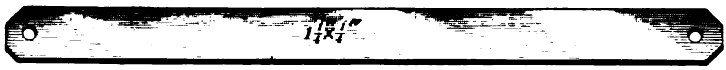


FIG. 27.

these to the pole and cross-arm is shown in Fig. 28, which represents a pole top equipped with three 6-pin standard

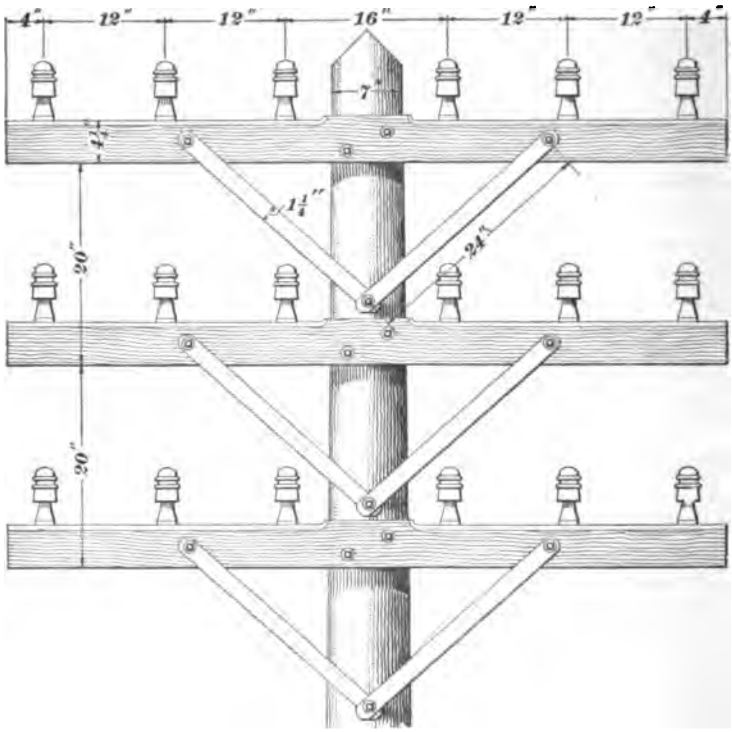


FIG. 28.

arms. The distance between the cross-arms is very often made 24 inches instead of 20 inches, as shown in Fig. 28. Each pair of cross-arm braces is secured to the pole by means of a single lag-screw and a washer, while the other ends are each secured to the cross-arm above by a $4'' \times \frac{5}{8}''$ carriage-bolt passing entirely through the cross-arm. A washer is provided under the head of the lag-screw and under the head and nut of each carriage-bolt.

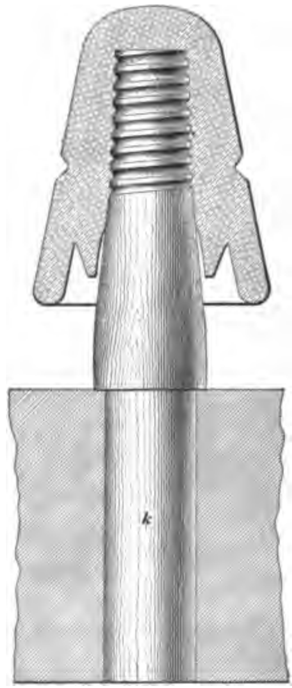


FIG. 29.

52. Brackets and Pins.—The pins by which insulators are mounted upon cross-arms are shown in Fig. 29. They may be made of locust, chestnut, or oak, being preferred in the order named, and are turned up with a coarse thread on the end on which the insulator is to be secured. The shank *k* is turned to $1\frac{1}{4}$ or $1\frac{1}{2}$ inches in diameter, according to the size of the hole in the arm. Standard cross-arms are usually bored for the $1\frac{1}{2}$-inch and the telephone arms for the $1\frac{1}{4}$-inch pins. The other dimensions of the pins are as follows:

Length of pin from base to shoulder	$3\frac{7}{8}$ to 4 inches.
Length of pin from shoulder to top	$4\frac{1}{8}$ to $4\frac{1}{2}$ inches.
Total length of pin	8 inches.
Length of thread	$2\frac{1}{8}$ inches.
Number of threads to the inch	5
Depth of threads	$\frac{1}{8}$ inch.

The pin should be secured in the hole by driving a nail through the arm and through the shank of the pin. This renders it difficult to extract the shank of the pin in case a new one is required, but, on the other hand, prevents the pin from pulling out, which sometimes occurs where this precaution is not taken. Steel pins are now being used extensively by some companies.

If only one or two wires are to be placed on the pole, brackets, shown in Fig. 30, are used. These are shaped at their lower ends in such a manner as to allow the pins to

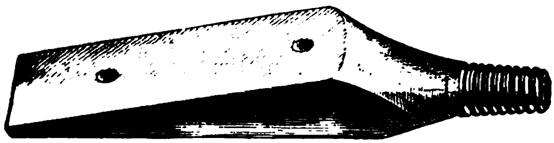


FIG. 30.

project from the pole at an angle, and are each provided with two holes, through which heavy spikes are driven to secure them to the pole.

53. Where a pole carries but few cross-arms, it is usually better to secure the arms and pins in place while the pole is on the ground, as it can be done much easier then than later, and the extra weight does not interfere seriously with the raising of the pole. In very heavy work, however, this can not be done, nor can it be done in cases where a pole must be raised through a network of wires, such as is frequently found in cities.

54. Lightning-Conductors. — It is a good plan to protect the line-wires from lightning discharges by putting conductors not less frequently than every tenth pole. Heavy, galvanized-iron wire should be used. About 10 feet of it should be formed into a flat coil, placed in the pole hole under the butt end of the pole; then the wire should be carried up and stapled to the pole on the side opposite the cross-arms, about 3 inches projecting above the top of the pole.

55. Depth of Pole Holes. — After the poles are on the ground and ready for raising, the pole hole should be dug. No absolute rule can be laid down for the depth to which pole holes should be dug, as this depends on the nature of the soil, the height of the poles, the number of wires to be carried, the number of poles to the mile, and the frequency of heavy wind-storms, and must, therefore, be left to a large extent to the judgment of the engineer. For average conditions, however, the following table, taken from Table 2, will serve as a guide for the depth of pole holes for various lengths of poles:

Length of Pole.	Depth of Hole.
25 ft.	5 ft.
30 to 35 ft.	5½ ft.
35 to 45 ft.	6 ft.
45 to 50 ft.	6½ ft.
50 to 60 ft.	7 ft.
60 ft. and over.	8 ft. and over.

56. Digging Pole Holes.—A hole should be started with the marking stake as a center, and should be of sufficient size to allow the pole to slip easily into place. About 2 inches all around each pole is the proper space to allow for tamping. If the holes are dug smaller than this, the probabilities are that they will not be properly tamped at the bottom.

57. In the construction of a pole line, it is a good plan to so proportion the work of the gang that poles will be set in all the holes dug, at the close of each day. Assuming that the average length of pole is 35 feet, a gang of about 6 men will be required for raising. These men may be all employed in digging holes in the morning, and, under average conditions, the same gang can in the afternoon set poles in all the holes dug in the line. It will therefore be well to provide six sets of digging tools, each set consisting of the following:

1 long-handled digging spoon.
1 long-handled round-pointed shovel.
1 combined crow and digging bar.

The digging spoon, shown in Fig. 31, should preferably have an 8-foot handle, the round-pointed shovel, shown in Fig. 32, a 7-foot handle, and the digging bar, shown in

Fig. 33, should be 8 feet long and constructed of $1\frac{1}{8}$-inch octagonal steel. It should be flattened at one end and pointed at the other. In some cases, various forms of post-hole augers have been found advantageous, but these can

FIG. 31.

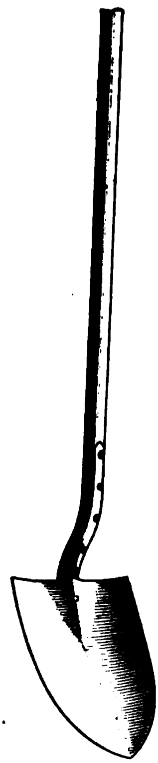


FIG. 32.

FIG. 33.

be used to advantage in few cases, and it is doubtful whether in the long run they give much more satisfactory results than the shovels and digging bars.

58. In average soil, one man can dig eight 6-foot holes in one day; of course, however, in very hard or rocky soil, this rate can not be even approached, so that it is a difficult matter to give a general estimate on work of this kind. The six men would, however, at the rate mentioned, dig 24 holes in half a day, and to raise and set that number of poles in the afternoon of the same day should be the aim of the foreman of the gang.

59. Raising Poles.—The following list of tools will usually comprise all those needed for an ordinary raising gang:

2 12-foot pike-poles.
2 14-foot pike-poles.
2 16-foot pike-poles.
2 dead-men, 6 and 8 feet in length, respectively.
1 cant-hook.
2 tamping-bars.
1 short-handled shovel.
2 carry hooks.
1 piece of oak plank 9 inches wide, 1½ inches thick, and 7 feet long.
1 set of 4-inch double-sheave block and tackle, with about 250 feet of ½-inch rope.

FIG. 34.

FIG. 35.

The pike-poles, shown in Fig. 34, are frequently of pine, and about 2½ inches in diameter at the largest end. At the opposite end is carried a pike of pointed steel projecting from the end of the pole about 3½ inches, and secured in place by a strong iron ferrule. The dead-man, shown in Fig. 35, consists of a short, heavy, oak bar about 4 inches in diameter and provided with a 2-tined fork, having a sharpened projection at the center to prevent slipping. This is used to support the pole during raising, while the men handling the pike-poles are securing new holds. The cant-hook, Fig. 36, consists of a short, stout bar of oak or hickory, to which is pivoted, at a point at about a foot from the end, an iron jaw provided with a spike, as shown. These are used in rolling the pole on the ground, or in turning it

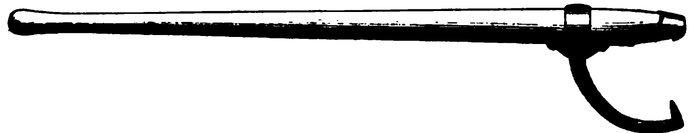


FIG. 36.

to the required position after it is raised. The carry hook, shown in Fig. 37, consists of two iron jaws pivoted and swiveled to the center of a stout oak handle about 5 feet long. These are used when it is necessary to carry the pole for short distances or to swing one end around into the proper position for raising. The oak plank is used for preventing the butt of the pole from crumbling away the

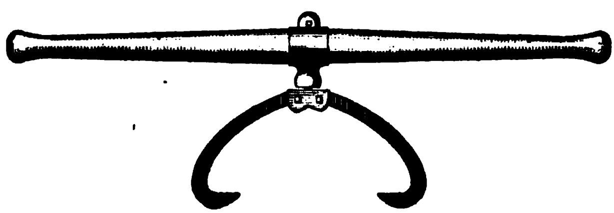


FIG. 37.

earth on the side of the hole during the process of raising. The block and tackle is frequently found convenient in pulling a pole up an embankment upon which it could not be placed directly from the wagon.

60. Before raising the pole, it should be rolled by means of cant-hooks or by any available means, so that its butt lies over the hole. The oak plank should be placed in the hole on the side farthest from the pole in such a manner as to form a guide for the butt of the pole in its descent. One man should then be assigned to the dead-man, four to the pike-poles, and one should be stationed at the hole, provided with a crowbar and cant-hook so as to be able to guide the pole into the hole in the proper manner and at the same time to instruct the raisers. The small end of the pole should then be raised by hand and supported by the dead-man while the men obtain a new hold. As they raise it higher and higher, the dead-man is moved towards the butt, at all times inclining slightly towards the butt, in order that it may have a tendency to push the pole towards the hole. When the pole is high enough to enable the use of the shorter pike-poles, the pikes of these should be planted firmly on the under side of the pole and the pole raised still higher, the dead-man at all times being kept in position in such manner as to ease the work of the men, and also to prevent accidents. As the pole is raised higher, the longer pikes may be used.

61. The method of using pike-poles and dead-man is shown in Fig. 38. The lower end of the pike-pole is placed

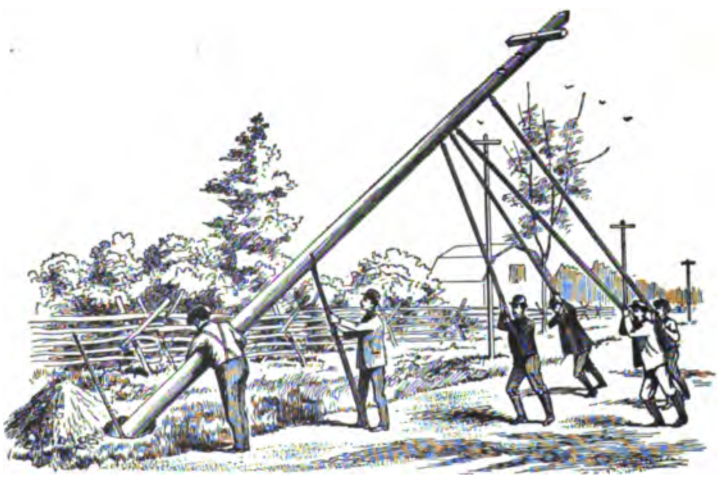


FIG. 38.

directly on the shoulder and held in that position by the hands. The pole should always have its upper end inclined towards the hole, and should be about in line with the body of the user, so as to allow him to push to the greatest advantage. The men should work as nearly under the pole as possible, but should spread out slightly so as to steady the pole from falling sidewise. As the pole is raised, the men should, one at a time, shift to a lower hold, in order that an undue strain may not be placed upon the others. The dead-man should at all times be kept in position to take its share of the load. When nearly raised, the longer pike-poles may be used to advantage, the change, of course, being made by one man at a time, as before.

62. Bracing the Pole.—After the pole is brought to a vertical position, it should be turned by means of a cant-hook until the cross-arms assume a position at right angles to the direction of the line. In doing this, it should be remembered that the alternate poles should have the cross-arms face in the opposite direction. The reason for this will be pointed out later. When in the proper position, and vertical, the pole may be braced by means of four of the pike-poles, having the pikes stuck in the pole at a distance of about 8 feet from the ground, and their other ends planted firmly in the ground.

63. Filling In and Tamping.—The pole is now in proper position for filling in, and this should be done slowly, by one man, using the short-handled shovel. Meanwhile the earth, as thrown in, must be thoroughly tamped by two men, so that it is firmly packed around the pole on all sides through the entire depth of the hole. Much trouble is often caused by inattention to this detail, and it is therefore better to provide only one shovel, in order that but one man may fill in while the others are tamping. If the earth is thrown in more rapidly than it can be properly tamped, it will soon settle and result in a loose pole and subsequent trouble.

While three of the men are engaged in the filling in and tamping, the others may proceed to the next pole, in order to place it in the proper position for raising. By an intelligent handling of the men, much time and expense may be saved, and therefore too much attention can not be given to the considerations as to how the work shall be proportioned among them.

64. Pole Foundations.—When marshy ground is encountered, it is frequently necessary to provide a suitable foundation for the pole. The method shown in Fig. 39 is often used, and for most cases will prove effective. The foot-plate is formed of 2-inch oak planks about 3 feet long and 12 inches wide, fastened together by heavy spikes. The hole is dug much larger than usual, and after its bottom is properly leveled, the foot-plate is put in place, and the pole set upon its center. Frequently a framework of 4″ × 4″ oak lumber is built around the pole on the surface of the ground after the pole is raised, and is securely fastened to the pole by long spikes and braced according to any available method.

FIG. 39.

65. In many cases, it is impossible to dig a pole hole to the depth required in the specifications. This is especially true in cities where subways, sewers, or pipe-lines frequently run close to the surface and directly under the position that the pole must occupy. When this is the case, the hole should be dug as deep as possible and from 4 to 5 feet in diameter. A layer from 6 inches to 1 foot deep of good cement concrete should be placed in the bottom, after which the pole should be raised and the hole filled in with concrete thoroughly tamped in place. The concrete used for this and similar purposes should be mixed according to the following formula:

1 part hydraulic cement.
2 parts sand.
5 parts screened gravel, broken stone, or broken brick.

The cement and sand should be first thoroughly mixed while dry, and then a sufficient quantity of water should be added to form a soft mortar; the gravel, stone, or brick should then be added and thoroughly mixed with it. The greatest diameter of the gravel, broken stone, or brick should not exceed 2 inches. It is well to remember that when the pieces of broken stone or gravel are not of uniform size, the concrete requires less cement, and is at the same time fully as strong as where the pieces of stone are of uniform size. The reason for this is that the smaller pieces help to fill the interstices between the larger ones, thus requiring less space to be filled with cement. All poles set either in marshy ground or in conditions requiring a cement foundation, should, if possible, be heavily guyed, in order to render them still more secure.

66. Guying.—It has already been stated that all poles upon which a turn in a line is made should be guyed in a direction to resist the strain of the line-wires upon them.

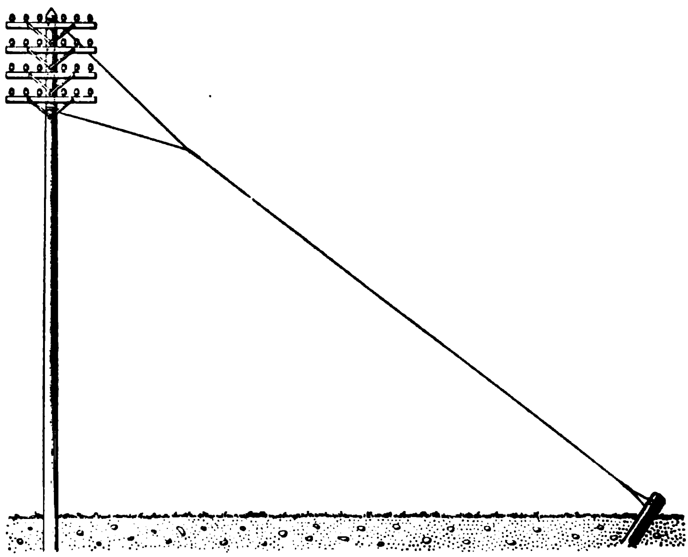


FIG. 40.

The guying should be done before any wires are strung, the guy wires being pulled up tight enough to give the pole a slight lean towards the guy stub or anchor. The methods of guying are numerous, and much must be left to the judgment of the construction man for its proper execution. The best form of side guy is that shown in Fig. 40, which is commonly known as the **Y** guy. Where the guy is attached only to the top of the pole, there is a tendency for the pole to bend, brought about by the strain of the line-wires attached below it. This strain is so great as to frequently cause poles guyed in this manner to break, this break usually occurring at the gain of the lower cross-arm. In a similar manner, if the guy wire extends to one point only, and that below the lower cross-arm, a similar strain in an opposite direction is placed upon the poles, which is likely to produce the same result. The **Y** guy effectually remedies this difficulty by evenly distributing the strain throughout the pole.

67. The strains brought about by the line-wires at every turn in the pole line are not the only ones that must be provided against. The side pressure due to wind is often very severe, and in countries subject to severe windstorms, side guys should be placed on both sides of the pole line at frequent intervals. This is especially true where heavy sleet storms occur, for the coating of ice formed upon wires often reaches 2 or 3 inches in diameter, and this not only adds enormously to the weight carried by the poles, but also to the wind resistance.

68. Head Guying.—Very heavy strains occur in the direction of the pole lines and must be provided against. Of course, the line-wires themselves tend to assume a large

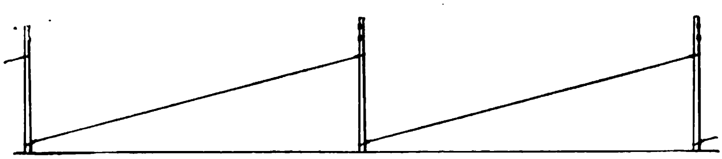


FIG. 41.

portion of this strain, but in heavy wind-storms they do not form a sufficient protection, and it is therefore well to guy the poles at frequent intervals against these strains. What is commonly termed **head guying** is chiefly resorted to for this purpose, and is shown in Fig. 41. In this, the top of each pole is guyed to the base of the next one to it, in the manner shown. After about three poles have been guyed

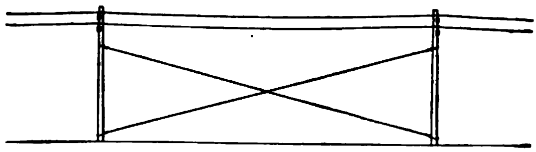


FIG. 42.

in this manner, the direction of the guy wires should be reversed on the next three, so that the longitudinal strain of the line-wires will be met in either direction. Another method of guying to resist longitudinal strains in either direction is shown in Fig. 42, and is known as double-head guying.

In telephone-lines carrying but few wires, head guying is not, under ordinary circumstances, used, but for heavy lines extending over long distances it is an exceedingly important matter. It frequently prevents a long section of line from going down in wind-storms, for, obviously, if one pole gives way, a severe strain is produced on all the poles, not only by the weight and tension of the line-wires, but also by the wind if it happens to be in that direction.

69. Facing of Cross-Arms. — The arrangement of cross-arms on opposite sides of alternate poles, which has already been mentioned, is a matter of great importance, and when done greatly assists in the prevention of undue longitudinal strains in the line. If a pole goes down on a line, and the cross-arms are all set in one direction, it is obvious that the cross-arms on all the poles on one side of the break might be pulled off the poles, while if they were alternately on opposite sides of the poles, only one span at most would fall, unless the pole should break, and this, of course, should be guarded against by head guying.

70. Anchors for Guy Wires.—The method of anchoring guy wires must be varied according to existing conditions. The most common method is the guy stub, which is placed in the ground, as shown in Fig. 43. The guy stub should conform to the same specifications as the poles regarding quality of wood, and are usually made from

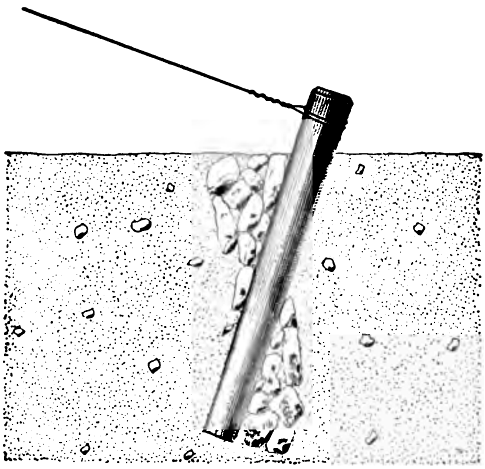


FIG. 43.

the parts of poles too crooked to be used as poles. For ordinary purposes, a guy stub should be not less than 8 inches in diameter at the small end, and from 7 to 10 feet in length. It is well in setting to wedge rocks in the hole, as shown, dirt being firmly tamped about them, as in pole setting.

71. Anchor Log and Rod.—Another common method of anchoring the guy wire is by means of the anchor log, placed as shown in Fig. 44. The anchor log may be made of the same material as the pole, and, as in the case of the guy stub, may be formed from a portion of a pole. Railroad-ties, where obtainable, are often used for this purpose. It should be from 4½ to 8 feet long, and not less than 30 inches in circumference. The anchor rod should be of good wrought iron, not less than ⅝ of an inch in diameter, and from 6 to 8 feet long. It should be threaded on its lower end for a heavy galvanized-iron nut, and should be further provided with a galvanized-iron washer $\frac{3}{8}$ inch in thickness and 4 inches square. The guy rod should pass directly through the center of the anchor log, as shown, and should

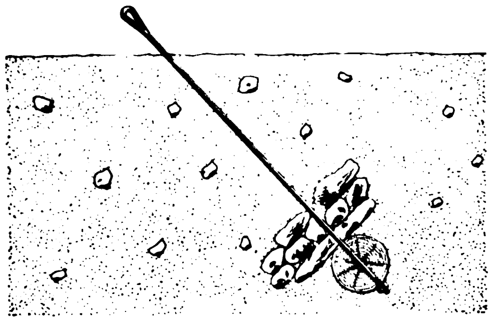


FIG. 44.

extend about 6 inches above the surface of the ground. In burying the anchor log, it is well to pile heavy rocks above it in a direction to meet the strain of the guy wire. Five or six feet is, in ordinary cases, a sufficient depth at which to place the anchor log.

72. Guying to Trees.—Where it becomes necessary to anchor to the base of a tree. heavy wooden blocks should

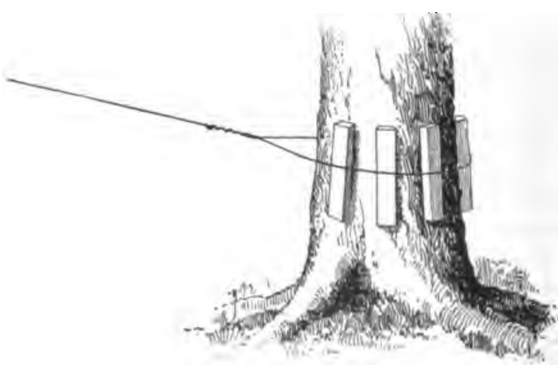


FIG. 45.

be placed, as shown in Fig. 45, at intervals about the tree, in order to prevent the tree being strangled by the guy wire, If this is properly done, the tree will not be injured, while a guy wire placed directly about the trunk of a tree will often kill it within a year. Considerations such as this should always be borne in mind, for right of way and guy-wire privileges are very hard to obtain, and a few instances where real damage is produced by their use will render subsequent privileges doubly so.

73. Guy Wires.—Under ordinary circumstances, two strands of No. 9 iron wire twisted together form a very satisfactory guy rope. In many cases, however, a single strand of No. 8 or No. 6 is used. It is better, however, and especially in heavy construction, to use a stranded rope manufactured especially for this and similar purposes. These ropes are commonly composed of 7 strands of steel wire, the external diameter of the rope varying from $\frac{3}{32}$ to $\frac{1}{2}$ inch, the most common sizes for guying being $\frac{1}{4}$ inch and $\frac{3}{8}$ inch.

FIG. 46.

In tying the guy wire about the pole or guy stub, it is customary to pass it twice around the pole or stub and then to

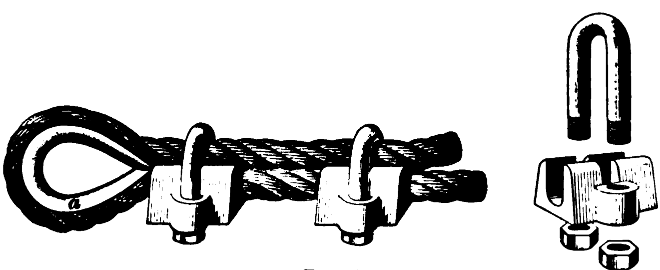


FIG. 47.

secure it by twisting the end around itself, as shown in Fig. 46. Where steel rope is used, the strands should be untwisted before the tie is made and then wound around the main rope in parallel layers, as clearly shown in the figure. A better method, however, of fastening a stranded guy rope is by means of wrought-iron clamps, as shown in Fig. 47, which are made especially for this purpose. Where the guy rope is to be attached to an eye, as, for instance, in the top of an anchor rod, a thimble *a*, such as that shown in Fig. 47, is used to form an eye in the rope, this being made to interlink with that of the anchor rod. Where, however, the guy wire is to be secured to the pole or to a guy stub, the thimble *a* is not used, but the wire rope passed twice around the pole as before, and then secured by means of the clamps.

74. Anchor Poles.—Where an overhead line ends, it is necessary to thoroughly anchor the last pole in order to counteract the strain brought upon it by the line-wires, which in this case will be all in one direction. These strains are frequently very great, so much so that it is sometimes a very difficult problem to provide means to adequately stand them. In some cases, structural-iron poles are built especially for the purpose, these being cross-braced by means of iron latticework, and thoroughly set, deep in the ground, in a large bed of concrete. This method, however, is very expensive, poles of this type costing from $150 to $800, according to the conditions to be met. A cheaper way, and one which, although much more expensive than the ordinary pole, is far less expensive than the structural-iron pole, is to use a composite pole such as is shown in Fig. 48. This consists of a very heavy, wooden pole braced at the top by means of an iron latticework, upon which the cross-arms are mounted, and to which the heavy, iron guy rods are fastened, as shown. A pole of this kind may be designed for meeting almost any strains that can be placed upon it. The particular pole shown was of Norway pine 70 feet long, 16 inches in diameter at the top and 22 inches at the butt, and set 10 feet below the surface. It was designed to carry 100 wires

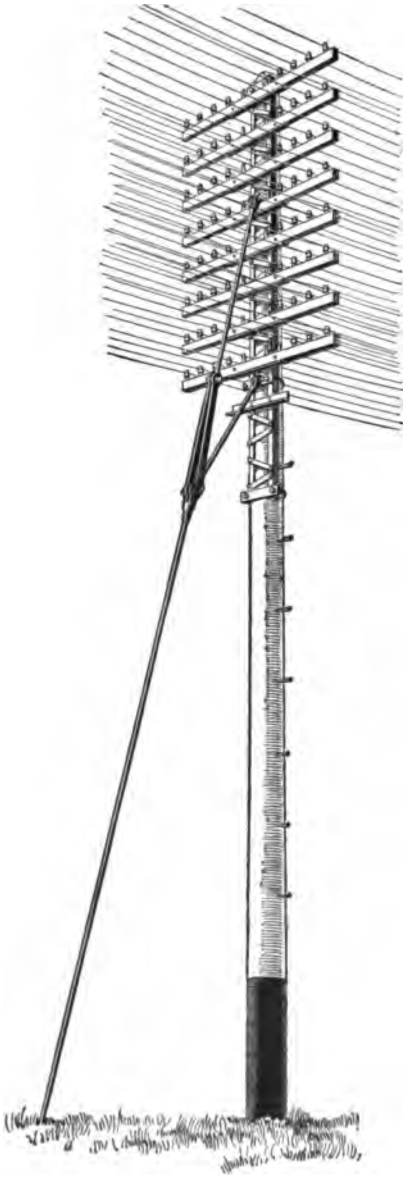


FIG. 48.

and 4 cables, all being dead-ended at this point. The latticework at the top was built of two 3″ × 7″ steel angle-irons connected together by diagonal lattice pieces. At intervals of 16 inches 3″ × 4″ angle-irons were set, upon which the cross-arms were mounted. This lattice is secured to the pole by means of U-shaped bands, to which the two branches of the guy rod are attached. The manner of setting this pole in the ground is shown in Fig. 49, a heavy oak platform being built around the base of the pole, as shown, and afterwards covered with earth or stone. The object of the latticework is to relieve the pole of all bending strain. The pole itself serves only to receive the downward component of the forces acting upon it, while the tension in the line-wires and cables is taken entirely by the heavy wrought-iron guy rod. Where poles of this description are used, it is of great importance that adequate measures shall be taken to prevent it from rotting, and therefore it is well to thoroughly coat the butt and the entire underground woodwork with tar.

The more expensive forms of anchor pole, such as have been described, are usually necessary only in cities. Where

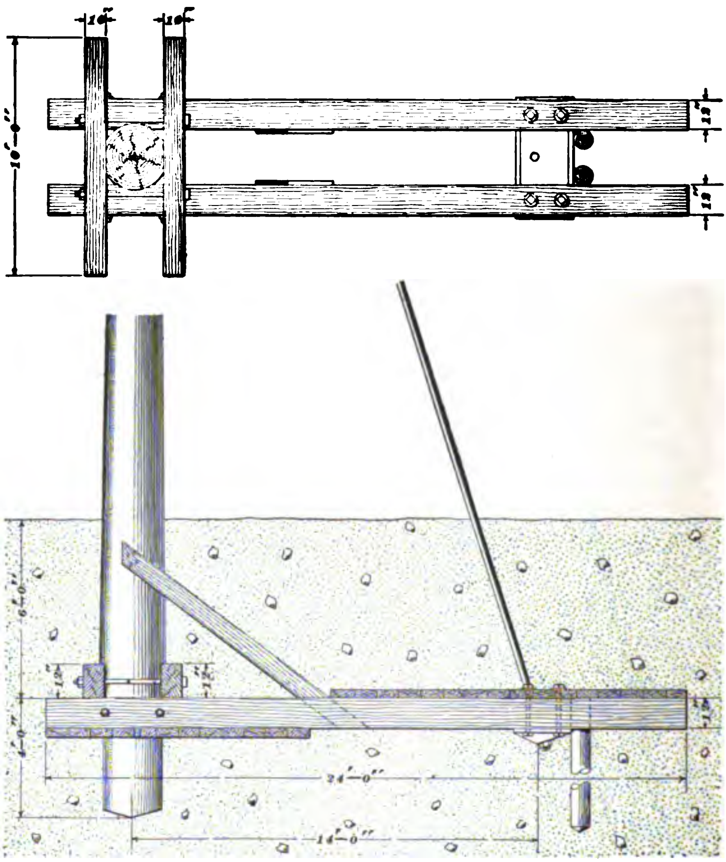


FIG. 49.

the lines are not too heavy, and where sufficient room may be had for planting a guy anchor, the method shown in Fig. 50 is used. The end pole is made very heavy, and is set deep in the ground and heavily guyed by a **Y** guy to a guy stub or any other available anchor. Each of the next five or six poles are then head guyed in a direction to resist the

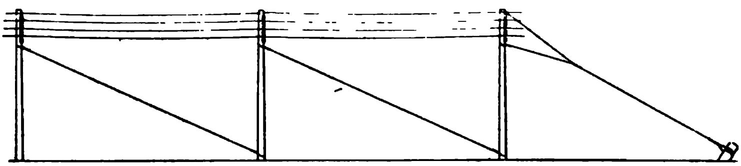


FIG. 50.

strain, thus all bearing a share of the excessive strain due to the wires.

INSULATORS.

75. Insulators in this country are usually made of glass, while in Europe porcelain is more commonly used. Porcelain when new is a better insulator than glass; but it is more costly, and under the action of cold the glazed surface becomes cracked. When this happens, the moisture soaks into the interior structure, and its insulating quality is greatly impaired. Tests recently made have shown that when newly put up, the insulation resistance of porcelain insulators is from 4 to 8 times better than glass, but that along railroads and in cities, smoke forms a thin film upon each material, so that at the end of a few months their insulating properties are nearly alike. On country roads away from railroad-tracks, the porcelain insulators maintain a higher insulation than the glass during rain-storms, but in fine weather it is not so high. Porcelain has an advantage over glass in that it is not so brittle, and therefore less likely to break when subjected to mechanical shocks. Porcelain does not condense and retain on its surface a thin film of moisture so readily as glass, i. e., it is less hygroscopic. On the other hand, however, glass insulators are not subject to such an extent as porcelain to the formation of cocoons and cobwebs under them, the transparency of the glass serving to allow sufficient light to pass through the insulator to render it an undesirable abode for spiders and worms. As cocoons, cobwebs, etc., serve to lower the insulation of the line to a great extent, this is an advantage which in this country it is not well to overlook.

76. The form of insulator shown in Fig. 29 and in Fig. 51 (*c*) is much used in telegraph, and somewhat in telephone, work. It is bell shaped, with an interior thread and a double petticoat. The object of the double petticoat is to form a long path over which leakage currents from the line

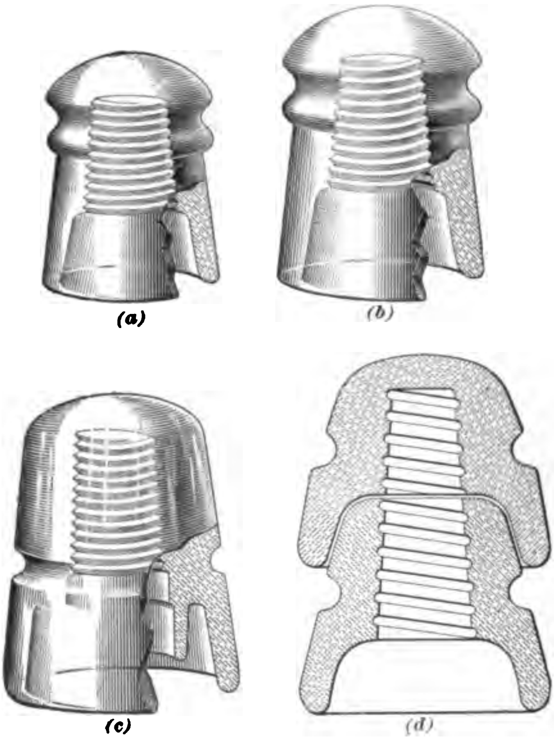


FIG. 51.

must pass before they reach the pin, and to keep the pin as dry as possible. The resistance of insulators follows the same law as the resistance of conductors. The longer the path afforded and the less its cross-section, the greater resistance will it offer to leakage currents from the line. A form of insulator shown in Fig. 51 (*a*), and known as the pony insulator, is much used for telephone-lines. While not having such a high resistance as the double-petticoat insulator, still it dries quicker after a rain, and, on the whole, gives good satisfaction for telephone-line work.

In Fig. 51 (*d*) is shown the Hibbard transposition insulator used by the Bell Companies. There is also made a good transposition insulator in one piece. Transposition insulators are necessarily large and somewhat heavy, generally requiring specially large and heavy pins.

The insulator shown in Fig. 51 (*b*) is a single-petticoat insulator, similar to (*a*), but larger. It is used more for telegraph-line work.

WIRES FOR TELEPHONE USE.

SIZES OF WIRE.

77. Before considering the advantages and disadvantages of the various kinds of wire, it will be necessary to discuss the different methods by which the sizes of wire are designated. Unfortunately, various standards or wire gauges have been adopted by different manufacturers, the result being a lack of unity in this direction, which frequently causes confusion.

78. Circular Measure.—The best method of designating the size of a wire is to express its diameter in *mils* and its cross-sectional area in *circular mils.*

79. A **mil** is a unit of length used in measuring the diameters of wires, and is equal to one-thousandth of an inch; that is, 1 mil = .001 inch.

80. A **circular mil** is a unit of area, and may be defined as the area of a circle the diameter of which is 1 mil. This method of expressing the area of cross-section of a wire is chosen in preference to expressing it in square inches, because a very simple relation exists between the circular mil and the diameter of a wire, so that either is more easily determined from the other than if the area were expressed in square inches.

The area of any circle in square measure is equal to

$$\pi r^2 = \frac{\pi d^2}{4},$$

where r is the radius and d the diameter of the circle.

If d is expressed in inches, the area $\pi \frac{d^2}{4}$ will be in square inches. If d is in mils, the area $\pi \frac{d^2}{4}$ will be in square mils. The area of a circle 1 mil in diameter is $\pi \frac{d^2}{4}$ square mils, and as d is equal to 1, we have 1 circular mil $= \frac{\pi}{4}$ square mils; and conversely, 1 square mil $= \frac{4}{\pi}$ circular mils. The area of any circle in circular mils will be equal to the area of that circle in square mils multiplied by the number of circular mils in 1 square mil; thus, the area of a circle d mils in diameter, expressed in circular mils, is equal to

$$A = \frac{\pi d^2}{4} \times \frac{4}{\pi} = d^2. \qquad (1.)$$

From this we see that the area of any circle expressed in circular mils is equal to the square of the diameter expressed in mils.

EXAMPLE.—What is the area in circular mils of a round wire having a diameter of .46 in.?

SOLUTION.— .46 in. = 460 mils. Since the area in mils is equal to the square of the diameter in mils, we have 460 × 460 = 211,600 circular mils. Ans.

EXAMPLE.—Find the area of a round copper rod having a diameter of $\frac{3}{16}$ of an inch.

SOLUTION.— $\frac{3}{16}$ in. = 187.5 mils. 187.5 × 187.5 = 35,156.25 circular mils. Ans.

81. If we know the area of a wire in circular mils, we may obtain the diameter in mils by extracting the square root of its area in circular mils.

EXAMPLE.—What is the diameter of a wire having a cross-sectional area of 1,021.5 circular mils?

SOLUTION.— $\sqrt{1,021.5} = 31.961$ mils = .031961 in. Ans.

82. As has been stated, various manufacturers have adopted different standards by which they designate the various numbers of their wires. These are usually termed wire gauges, and in each gauge a particular number refers to a wire having a certain diameter. The size of wire generally decreases as the gauge number increases, but the law by which this decrease occurs is not the same in the different gauges.

83. The Brown & Sharpe, or American, Gauge. —This gauge is usually termed B. & S., and copper wire is usually designated according to it in the United States. The rule by which the sizes of wire increase as the gauge number diminishes is a very simple one in this gauge, and considering this simplicity, it is surprising that so few people understand it. If we take any gauge number as a basis of comparison, then by adding 3 to the gauge number we obtain the number of a wire having very nearly ½ the cross-sectional area. To illustrate: One No. 7 wire will have the same cross-sectional area as two No. 10's, as four No. 13's, as eight No. 16's, and so on. Similarly, by subtracting 3 from any gauge number, we obtain the number of a wire having very nearly twice the cross-sectional area. Thus, one No. 1 has twice the area of a No. 4; one No. 10 has twice the area of a No. 13. A little study will show that the ratio between the area of each wire and the next smaller or larger is equal to the cube root of 2, or 1.26, for in order to obtain the size of a wire of twice the area of a given wire, we must multiply the area of the given wire by this ratio three times; therefore the cube of the ratio must be equal to 2.

From the above, we may deduce the following rules, remembering that the resistance of a wire varies inversely as its cross-sectional area:

84. Rule.—*The ratio between the resistance of any wire in the B. & S. gauge and that of the next higher number is that of 1 to 1.26.*

85. Rule.—*The ratio between the resistance of any wire in the B. & S. gauge and that of the next lower number is that of 1.26 to 1.*

86. A wire three sizes smaller than a given wire will have a resistance twice as great, and a wire three sizes larger will have a resistance one-half as great as that of the given wire.

EXAMPLE.—Find the resistance of 1,000 ft. of No. 16 B. & S. gauge copper wire, having given that the resistance of 1,000 ft. of No. 10 wire is 1 ohm.

SOLUTION.—No. 16 is six sizes smaller than No. 10, and will therefore have $2 \times 2 = 4$ times the resistance. $4 \times 1 = 4$ ohms. Ans.

EXAMPLE.—The resistance of a No. 12 B. & S. gauge copper wire is 8.37 ohms per mile. What is the resistance (*a*) of a mile of No. 11? (*b*) of a mile of No. 13?

SOLUTION.—(*a*) $8.37 \div 1.26 = 6.64$ ohms. Ans.
(*b*) $8.37 \times 1.26 = 10.54$ ohms. Ans.

EXAMPLE.—The resistance of a No. 00 B. & S. gauge copper conductor is .411 ohm per mile. What is the resistance of a similar conductor of No. 3 gauge?

SOLUTION.—The third size smaller than No. 00 is No. 2. The resistance of No. 2 per mile is, therefore, $2 \times .411 = .822$ ohm. The resistance of No. 3 is 1.26 times that of No. 2, or $.822 \times 1.26 = 1.036$ ohms. Ans.

87. It is a very convenient fact to remember that the diameter of a No. 10 wire in the B. & S. gauge is very close to $\frac{1}{10}$ of an inch (.10189), and that its resistance per thousand feet is practically 1 ohm (1.0199). For rough values, one can, by remembering these facts, compute the resistance in cross-sectional area of any other size in the B. & S. gauge without using the table. For accurate calculations, however, it is always better to consult a table giving the various properties of different sizes.

TABLE 4.

DIFFERENT STANDARDS FOR WIRE GAUGE IN USE IN THE UNITED STATES.

Dimensions of Wires in Decimal Parts of an Inch.

Number of Wire Gauge.	American, or Brown & Sharpe.	Birmingham, or Stubs.	Washburn & Moen M'f'g Co., Worcester, Mass.	Trenton Iron Co., Trenton, N. J.	G. W. Prentiss, Holyoke, Mass.	Old English, from Brass Mfrs'. List.	British Standard.	Number of Wire Gauge.
000000	....	....	.4600	....	....	....	....	000000
00000	....	....	.4300	.4500	....	....	....	00000
0000	.460000	.454	.3930	.4000	....	....	....	0000
000	.409640	.425	.3620	.3600	.3586	....	....	000
00	.364800	.380	.3310	.3300	.3282	....	....	00
0	.324860	.340	.3070	.3050	.2994	....	....	0
1	.289300	.300	.2830	.2850	.2777	....	....	1
2	.257630	.284	.2630	.2650	.2591	....	....	2
3	.229420	.259	.2440	.2450	.2401	....	....	3
4	.204310	.238	.2250	.2250	.2230	....	.2320	4
5	.181940	.220	.2070	.2050	.2047	....	.2120	5
6	.162020	.203	.1920	.1900	.1885	....	.1920	6
7	.144280	.180	.1770	.1750	.1758	....	.1760	7
8	.128490	.165	.1620	.1600	.1605	....	.1600	8
9	.114430	.148	.1480	.1450	.1471	....	.1440	9
10	.101890	.134	.1350	.1300	.1351	....	.1280	10
11	.090742	.120	.1200	.1175	.1205	....	.1160	11
12	.080808	.109	.1050	.1050	.1065	....	.1040	12
13	.071961	.095	.0920	.0925	.0928	....	.0920	13
14	.064084	.083	.0800	.0800	.0816	.08300	.0800	14
15	.057068	.072	.0720	.0700	.0726	.07200	.0720	15
16	.050820	.065	.0630	.0610	.0627	.06500	.0640	16
17	.045257	.058	.0540	.0525	.0546	.05800	.0560	17
18	.040303	.049	.0470	.0450	.0478	.04900	.0480	18
19	.035890	.042	.0410	.0400	.0411	.04000	.0400	19
20	.031961	.035	.0350	.0350	.0351	.03500	.0360	20
21	.028462	.032	.0320	.0310	.0321	.03150	.0320	21
22	.025347	.028	.0280	.0280	.0290	.02950	.0280	22
23	.022571	.025	.0250	.0250	.0261	.02700	.0240	23
24	.020100	.022	.0230	.0225	.0231	.02500	.0220	24
25	.017900	.020	.0200	.0200	.0212	.02300	.0200	25
26	.015940	.018	.0180	.0180	.0194	.02050	.0180	26
27	.014195	.016	.0170	.0170	.0182	.01875	.0164	27
28	.012641	.014	.0160	.0160	.0170	.01650	.0148	28
29	.011257	.013	.0150	.0150	.0163	.01550	.0136	29
30	.010025	.012	.0140	.0140	.0156	.01375	.0124	30
31	.008928	.010	.0135	.0130	.0146	.01225	.0116	31
32	.007950	.009	.0130	.0120	.0136	.01125	.0108	32
33	.007080	.008	.0110	.0110	.0130	.01025	.0100	33
34	.006304	.007	.0100	.0100	.0118	.00950	.0092	34
35	.005614	.005	.0095	.0095	.0109	.00900	.0084	35
36	.005000	.004	.0090	.0090	.0100	.00750	.0076	36
37	.004453	....	.0085	.0085	.0095	.00650	.0068	37
38	.003965	....	.0080	.0080	.0090	.00575	.0060	38
39	.003531	....	.0075	.0075	.0083	.00500	.0052	39
40	.003144	....	.0070	.0070	.0078	.00450	.0048	40
41	....	....	....	....	....	....	.0044	41
42	....	....	....	....	....	....	.0040	42

88. Other Wire Gauges.—Besides the Brown & Sharpe gauge, the following have been or are used to a considerable extent: Birmingham, or Stubs wire gauge, abbreviated B. W. G.; Washburn & Moen Mfg. Company's gauge; Trenton Iron Company's gauge; G. W. Prentiss' gauge; British Standard gauge, abbreviated S. W. G., and the old English gauge. Table 4 shows the diameters of the wires of the different gauge numbers according to each of these standards.

CONDUCTIVITY.

89. The **specific resistance** of a conductor is the resistance between the opposite faces of a cube 1 centimeter square of the given substance at a temperature of 0° C., or 32° F. Table 5 gives the resistances of the more common metals in microhms, or millionths of an ohm, per cubic centimeter, at a temperature of 0° C.

TABLE 5.

Metal.	Resistance.	Metal.	Resistance.
Silver, annealed	1.504	Iron, annealed	9.716
Copper, annealed	1.598	Nickel, annealed	12.470
Silver, hard-drawn	1.634	Tin, pressed	13.210
Copper, hard-drawn	1.634	Lead, pressed	19.630
Gold, annealed	2.058	German Silver	20.930
Gold, hard-drawn	2.094	Antimony, pressed	35.500
Aluminum, annealed	2.912	Mercury	94.320
Zinc, pressed	5.626	Bismuth, pressed	131.200
Platinum, annealed	9.057		

90. The **specific conductivity** of a conductor is the reciprocal of its specific resistance.

The **percentage conductivity of a conductor** is the ratio that its specific conductivity bears to that of some standard conductor, usually pure copper, the conductivity of the latter being taken as 100.

91. The **percentage conductivity of a wire** is the ratio the conductivity of that wire bears to the conductivity of a *pure copper* wire at the same temperature and of the same length and weight, the conductivity of the latter being taken as 100. The percentage conductivity is frequently used in specifications as to the quality of copper wire, it being a frequent requirement that the wire shall have a conductivity equal to 98 per cent. of that of pure copper.

92. The Mile-Ohm.—A convenient standard for expressing the conducting quality of wires of a given metal, regardless of the size of the wires, is what is commonly termed the mile-ohm, or, more properly, the weight per mile-ohm. When the weight per mile-ohm of a certain quality of metal is referred to, the weight of a circular wire 1 mile long and of such a size as to have a resistance of 1 ohm is meant. Obviously, the better the conducting quality of the metal, the smaller will be the weight per mile-ohm, for a wire a mile long having a resistance of 1 ohm will be of smaller diameter if the metal is a good conductor than if it is a poor conductor.

It is not uncommon to say that the weight per mile-ohm of a certain grade of copper wire is, say, 888 pounds at a temperature of 60°, or that the weight per mile-ohm of a certain grade of iron wire is 6,500 pounds. These expressions mean, in the first case, that a wire made of this grade of copper, 1 mile long, having a resistance of 1 ohm, would weigh 888 pounds, and in the second case, that the wire made of that grade of iron, 1 mile long, and having a resistance of 1 ohm, would weigh 6,500 pounds.

93. The weight per mile-ohm of a metal forms a convenient basis for determining the percentage conductivity;

for, since the weight of a given wire varies as its cross-section, and since the conductivity varies directly as the cross-section, it follows that the conductivity of two wires will be inversely proportional to their respective weights per mile-ohm. Thus, if we know that the weight per mile-ohm of pure copper at 60° F. is 871 pounds, while the weight per mile-ohm of a sample is 888 pounds, then the percentage conductivity may be found from the following proportion, remembering that the conductivity of pure copper is 100:

$$X : 100 :: 871 : 888,$$

or

$$X = \frac{871}{888} \times 100 = 98.08,$$

where X is the percentage conductivity.

94. If we know the resistance per mile of a given wire, and also the weight per mile-ohm of that metal, then we may determine the weight of the wire per mile by dividing the weight per mile-ohm by the resistance per mile. On the other hand, if the weight per mile is known, the resistance per mile may be ascertained by dividing the weight per mile-ohm by the weight per mile. Thus, an iron wire weighing 204 pounds per mile, made from metal having a weight per mile-ohm equal to 6,500 pounds, will have a resistance equal to

$$\frac{6,500}{204} = 31.86 \text{ ohms.}$$

EXAMPLE.—If the weight per mile-ohm of a pure copper wire is 871.17 pounds at 60° F., and the weight per mile-ohm of an iron wire is 4,600 pounds, what is the percentage conductivity of the iron wire, pure copper being taken as a standard?

SOLUTION.—Calling X the percentage conductivity of the iron wire, we have

$$X : 100 :: 871.17 : 4,600;$$

that is,

$$X = \frac{871.17 \times 100}{4,600} = 18.93. \text{ Ans.}$$

EXAMPLE.—A piece of copper wire 1,000 feet long weighs 31.43 pounds and has a resistance of 1.0199 ohms at a temperature of 60°. What is its percentage conductivity, having given that the weight per mile-ohm of pure copper at 60° is 871.177 pounds?

SOLUTION.—Weight per mile of sample is

$$\frac{31.43 \times 5,280}{1,000} = 165.95 \text{ pounds.}$$

The resistance per mile of sample is

$$\frac{1.0199 \times 5,280}{1,000} = 5.385.$$

The weight per mile-ohm of the sample is equal to the weight per mile times the resistance per mile, or

$$165.95 \times 5.385 = 893.64 \text{ pounds.}$$

The percentage conductivity of the sample is then equal to

$$\frac{871.177 \times 100}{893.64} = 97.48. \quad \text{Ans.}$$

COPPER WIRE.

95. Copper wire is now universally used in all good telephone-construction work. Reference to Table 5 will show that copper has the lowest specific resistance, and therefore the greatest specific conductivity, of any metal except silver. This feature alone would tend to make copper the most valuable of metals for electric-transmission purposes, excepting silver, which is but slightly better, and which is unavailable on account of its high cost.

96. Pure annealed copper has a specific gravity of 8.89 at 60° F. One cubic inch weighs 0.32 pound, and its melting-point is about 2,100° F. As first manufactured, copper wire did not possess enough tensile strength to well adapt it for line-wire, and for that reason and because of its greater expense, it was used but little for that purpose. The process of hard-drawing copper wire has, however, greatly increased its tensile strength without seriously injuring its conductivity.

The weight per mile of a copper wire is given by the formula

$$W = \frac{d^2}{62.5}, \qquad (2.)$$

where d is the diameter in mils and W the weight in pounds per mile.

The resistance per mile in ohms of any pure copper wire at 75° F. is given by the formula

$$R = \frac{56,970}{d^2}, \qquad (3.)$$

where d is the diameter in mils and R the resistance per mile in ohms.

EXAMPLE.—What is the weight per mile of a copper wire 80.808 mils in diameter?

SOLUTION.—Weight $= \frac{(80.808)^2}{62.5} = 104.48$ pounds per mile. Ans.

EXAMPLE.—What is the resistance per mile (at 75° F.) of a copper wire 102 mils in diameter?

SOLUTION.—Resistance per mile $= \frac{56,970}{(102)^2} = 5.476$ ohms per mile. Ans.

97. Matthiessen's Standard.—Tables giving the resistance of the various sizes of copper wire are usually based on the grade of wire used by Dr. Matthiessen in determining the resistance of copper. The conductivity of the wire used by Dr. Matthiessen was at one time the highest known, but copper wire has since been produced having a somewhat higher conductivity. Matthiessen found that a piece of soft copper wire 1 foot long, and having a uniform diameter of .001 of an inch, had a resistance of 9.612 legal ohms at a temperature of 0° C. Such a piece of wire is termed a mil-foot, meaning that its diameter is 1 mil and its length 1 foot. Inasmuch as there are three different standard ohms, the British Association or B. A. ohm, the legal ohm, and the international ohm, it is well to give the values of Matthiessen's standard in all of them. Table 6 is taken from the report of the Standard Wiring Table Committee of the American Institute of Electrical Engineers, and gives the resistances, at 0° C., not only of the mil-foot, but of the meter-gram, the meter-millimeter, and the cubic centimeter.

TABLE 6.

MATTHIESSEN'S STANDARD.

Dimensions of Standard.	Resistance at 0° C.		
	B. A. Ohms.	Legal Ohms.	International Ohms.
Meter-gram soft copper.....	.14365	.14206	.14178
Meter-millimeter soft copper	.02057	.02035	.02030
Cubic centimeter soft copper	.000001616	.000001598	.000001594
Mil-foot soft copper.........	9.72	9.612	9.590

98. Tables 7 and 8 give the resistances and weights for all sizes of copper wire, according to the B. & S. and the B. W. gauges, respectively. These tables are based upon Matthiessen's standard.

99. Temperature Coefficient.—The temperature coefficient for pure copper is .0021 for a change of 1° F. This figure is exact enough for a correction to 60° or 75° F. for all ranges of temperature that occur in the testing room; but for ranges below 50° F. or above 100° F., it is better to consult a table. Table 9 gives the constants by which the resistance of a copper conductor (at the observed temperature) must be multiplied to correct its resistance to 75° F.

EXAMPLE.—The observed resistance of a copper wire is 12.746 ohms at 88° F. What is its resistance at 75° F.?

SOLUTION.—For 88° F. we find, from Table 9, that the multiplying factor is .9728; therefore, 12.746 × .9728 = 12.399 ohms. Ans.

TABLE 7.

Gauge No.—B. & S.	Diameter in Mils, or $\frac{1}{1000}$ Inch.	Area in Circular Mils. C. M. = d^2.	Area in Square Inches Area = $\frac{d^2}{1,000,000} \times .7854$.	Weights—Specific Gravity, 8.89.				Resistance at 68° F., in International Ohms, Based Upon Matthiessen's Standard.				
				Pounds per 1,000 Feet.	Pounds per Mile.	Feet per Pound.	Ohms per Pound, Annealed.	Ohms per 1,000 Feet.		Ohms per Mile.		Feet per Ohm, Annealed.
	d	d^2						Pure Annealed.	Hard Drawn.	Pure Annealed.	Hard Drawn.	
0000	460.000	211,600.00	.1661900000	640.50000	3,381.400	1.561	.00007639	.04893	.050036	.25835	.26419	20,440.000
000	409.640	167,805.00	.1317900000	508.00000	2,682.200	1.969	.00012150	.06170	.063094	.32577	.33314	16,210.000
00	364.800	133,079.40	.1045200000	402.80000	2,126.800	2.482	.00019310	.07780	.079558	.41079	.42007	12,850.000
0	324.865	105,534.50	.0828870000	319.50000	1,686.900	3.130	.00030710	.09811	.100330	.51802	.52973	10,190.000
1	289.300	83,694.20	.0657320000	253.30000	1,337.200	3.947	.00048830	.12370	.126490	.65314	.66790	8,083.000
2	257.630	66,373.00	.0521280000	200.90000	1,060.600	4.977	.00077650	.15600	.159530	.82368	.84239	6,410.000
3	229.420	52,634.00	.0413390000	159.30000	841.090	6.276	.00123500	.19670	.201140	1.03860	1.06210	5,084.000
4	204.310	41,742.00	.0327840000	126.40000	667.390	7.914	.00196300	.24800	.253610	1.30940	1.33920	4,031.000
5	181.940	33,102.00	.0259990000	100.20000	529.060	9.980	.00312200	.31280	.319870	1.65160	1.68890	3,197.000
6	162.020	26,250.50	.0206180000	79.46000	419.550	12.580	.00496300	.39440	.403320	2.08250	2.12950	2,535.000
7	144.280	20,816.00	.0163510000	63.02000	332.750	15.870	.00789200	.49730	.508540	2.62580	2.68500	2,011.000
8	128.490	16,509.00	.0129670000	49.98000	263.890	20.010	.01255000	.62710	.641270	3.31110	3.38590	1,595.000
9	114.430	13,094.00	.0102830000	39.63000	209.240	25.230	.01995000	.79080	.808760	4.17530	4.27690	1,265.000
10	101.890	10,381.00	.0081548000	31.43000	165.950	31.820	.03173000	.99720	1.019900	5.26570	5.38480	1,003.000
11	90.742	8,234.00	.0064656000	24.93000	131.630	40.120	.05045000	1.25700	1.285400	6.63690	6.78690	795.300
12	80.808	6,529.90	.0051287000	19.77000	104.390	50.590	.08022000	1.58600	1.621800	8.37410	8.56330	630.700

13	71.961	5,178.40	.0040672000	15.68000	82.791	63.790	.12760000	1.99900	2.044300	10.55500	10.79400	500.100
14	64.084	4,106.80	.0032254000	12.43000	76.191	80.440	.20280000	2.52100	2.577900	13.31100	13.61200	396.600
15	57.068	3,256.70	.0025579000	9.85800	52.050	101.400	.32250000	3.17900	3.250800	16.78500	17.16500	314.500
16	50.820	2,582.90	.0020285000	7.81800	41.277	127.900	.51280000	4.00900	4.099600	21.16800	21.64600	249.400
17	45.257	2,048.20	.0016087000	6.20000	32.736	161.300	.81530000	5.05500	5.169200	26.69100	27.29400	197.800
18	40.303	1,624.30	.0012757000	4.91700	25.960	203.400	1.29600000	6.37400	6.518300	33.65500	34.41600	156.900
19	35.890	1,288.10	.0010117000	3.89900	20.595	256.500	2.06100000	8.03800	8.219600	42.44100	43.40000	124.400
20	31.961	1,021.50	.0008023100	3.09200	16.324	323.400	3.27800000	10.14000	10.372000	53.53900	54.74900	98.660
21	28.462	810.10	.0006362600	2.45200	12.946	407.800	5.21200000	12.78000		67.47900		78.240
22	25.347	642.40	.0005045700	1.94500	10.268	514.200	8.28700000	16.12000		85.11400		62.050
23	22.571	509.45	.0004001500	1.54200	8.142	648.400	13.18000000	20.32000		107.29000		49.210
24	20.100	404.01	.0003173300	1.22300	6.457	817.600	20.95000000	25.63000		135.53000		39.020
25	17.900	320.40	.0002516600	.96990	5.121	1,031.000	33.32000000	32.31000		170.59000		30.950
26	15.940	254.10	.0001995800	.76920	4.061	1,300.000	52.97000000	40.75000		215.16000		24.540
27	14.195	201.50	.0001582700	.61000	3.221	1,639.000	84.23000000	51.38000		271.29000		19.460
28	12.641	159.79	.0001255100	.48370	2.554	2,067.000	133.90000000	64.79000		242.09000		15.430
29	11.257	126.72	.0000995360	.38360	2.025	2,607.000	213.00000000	81.70000		431.37000		12.240
30	10.025	100.50	.0000789360	.30420	1.606	3,287.000	338.60000000	103.00000		543.84000		9.707
31	8.928	79.70	.0000625990	.24130	1.274	4,145.000	538.40000000	129.90000		685.87000		7.698
32	7.950	63.21	.0000496430	.19130	1.010	5,227.000	856.20000000	163.80000		864.87000		6.105
33	7.080	50.13	.0000393680	.15170	.801	6,591.000	1,361.00000000	206.60000		1,090.80000		4.841
34	6.305	39.75	.0000312210	.12030	.635	8,311.000	2,165.00000000	260.50000		1,375.50000		3.839
35	5.615	31.52	.0000247590	.09543	.504	10,480.000	3,441.00000000	328.40000		1,734.00000		3.045
36	5.000	25.00	.0000196350	.07568	.400	13,210.000	5,473.00000000	414.20000		2,187.00000		2.414
37	4.453	19.83	.0000155740	.06001	.317	16,660.000	8,702.00000000	522.20000		2,757.30000		1.915
38	3.965	15.72	.0000123450	.04759	.251	21,010.000	13,870.00000000	658.50000		3,476.80000		1.519
39	3.531	12.47	.0000097923	.03774	.199	26,500.000	22,000.00000000	830.40000		4,384.50000		1.204
40	3.145	9.89	.0000077634	.02993	.158	33,410.000	34,980.00000000	1,047.00000		5,528.20000		.955

TABLE 8.

COPPER WIRE—BIRMINGHAM WIRE GAUGE.

Gauge No. (B. W. G.)	Diameters in Mils, or $\frac{1}{1000}$ Inch.	Area in Circular mils, C. M. = d^2.	Weights.		Resistances in International Ohms, Based Upon Matthiessen's Standard at 68° F.	
			1,000 Feet.	Mile.	Ohms per 1,000 Feet.	Ohms per Pound.
0000	454	206,116	624.000	3,294.000	.05023	.00008051
000	425	180,625	547.000	2,887.000	.05732	.00010480
00	380	144,400	437.000	2,308.000	.07170	.00016400
0	340	115,600	350.000	1,847.000	.08957	.00025600
1	300	90,000	272.000	1,438.000	.11500	.00042230
2	284	80,656	244.000	1,289.000	.12840	.00052580
3	259	67,081	203.000	1,072.000	.15430	.00076010
4	238	56,644	171.000	905.000	.18280	.00106600
5	220	48,400	146.000	773.000	.21390	.00146000
6	203	41,209	125.000	659.000	.25130	.00201400
7	180	32,400	98.000	518.000	.31960	.00325800
8	165	27,225	82.000	435.000	.38030	.00461500
9	148	21,904	66.000	350.000	.47270	.00712900
10	134	17,956	54.000	287.000	.57660	.01061000
11	120	14,400	44.000	230 000	.71900	.01650000
12	109	11,881	36.000	190.000	.87150	.02423000
13	95	9,025	27.300	144.000	1.14700	.04199000
14	83	6,889	20.800	110.000	1.50300	.07207000
15	72	5,184	15.700	83.000	1.99700	.12730000
16	65	4,225	12.800	68.000	2.45100	.19160000
17	58	3,364	10.200	54.000	3.07800	.30230000
18	49	2,401	7.300	38.400	4.31200	.59330000
19	42	1,764	5.300	28.200	5.87000	1.09900000
20	35	1,225	3.700	19.600	8.45200	2.27900000
21	32	1,024	3.100	16.400	10.11000	3.26200000
22	28	784	2.400	12.500	13.21000	5.56500000
23	25	625	1.900	10.000	16.57000	8.75600000
24	22	484	1.500	7.700	21.39000	14.60000000
25	20	400	1.200	6.400	25.88000	21.38000000
26	18	324	.980	5.200	31.96000	32.58000000
27	16	256	.770	4.100	40.45000	52.19000000
28	14	196	.590	3 100	52.83000	89.04000000
29	13	169	.510	2.700	61.27000	119.80000000
30	12	144	.440	2.300	71.90000	165.00000000
31	10	100	.300	1.600	103.50000	342.00000000
32	9	81	.250	1.300	127.80000	521.30000000
33	8	64	.190	1.020	161.80000	835.10000000
34	7	49	.150	.780	211.30000	1,425.00000000
35	5	25	.076	.400	414.20000	5,473.00000000
36	4	16	.048	.256	647.10000	13,360.00000000

TABLE 9.

Temperature in Degrees F.	Factor.	Temperature in Degrees F.	Factor.	Temperature in Degrees F.	Factor.	Temperature in Degrees F.	Factor.
100	.9484	82	.9853	64	1.0236	46	1.0634
99	.9504	81	.9874	63	1.0258	45	1.0657
98	.9524	80	.9895	62	1.0280	44	1.0679
97	.9544	79	.9916	61	1.0301	43	1.0702
96	.9564	78	.9937	60	1.0323	42	1.0725
95	.9585	77	.9958	59	1.0345	41	1.0748
94	.9605	76	.9979	58	1.0367	40	1.0771
93	.9626	75	1.0000	57	1.0389	39	1.0793
92	.9646	74	1.0021	56	1.0411	38	1.0816
91	.9666	73	1.0042	55	1.0433	37	1.0839
90	.9687	72	1.0064	54	1.0455	36	1.0862
89	.9708	71	1.0085	53	1.0478	35	1.0885
88	.9728	70	1.0106	52	1.0500	34	1.0908
87	.9749	69	1.0128	51	1.0522	33	1.0932
86	.9769	68	1.0149	50	1.0544	32	1.0954
85	.9790	67	1.0160	49	1.0567		
84	.9811	66	1.0193	48	1.0589		
83	.9832	65	1.0214	47	1.0612		

100. Strength of Copper Wire.—Good hard-drawn copper wire will support three times its own weight in pounds per mile. Thus, a No. 10 B. & S. gauge, copper wire weighing 166 pounds per mile will have a breaking strength of $3 \times 166 = 498$. In making specifications for copper line-wire, it is customary to require that it shall have a breaking strength equal to at least $2\frac{1}{2}$ times its weight per mile.

Table 10 gives the tensile strength of the various sizes in the B. & S. gauge of both hard-drawn and annealed copper wire. The breaking strengths of all but the largest sizes in this table were calculated upon the basis that soft wire has a tensile strength of 34,000 pounds per square inch and that the hard-drawn wire has a tensile strength of 60,000 pounds per square inch.

TABLE 10.

TENSILE STRENGTH OF COPPER WIRE.

Numbers. B. & S. Gauge.	Breaking Weight in Pounds.		Numbers. B. & S. Gauge.	Breaking Weight in Pounds.	
	Hard-Drawn.	Annealed.		Hard-Drawn.	Annealed.
0000	8,310	5,650	9	617	349
000	6,580	4,480	10	489	277
00	5,226	3,553	11	388	219
0	4,558	2,818	12	307	174
1	3,746	2,234	13	244	138
2	3,127	1,772	14	193	109
3	2,480	1,405	15	153	87
4	1,967	1,114	16	133	69
5	1,559	883	17	97	55
6	1,237	700	18	77	43
7	980	555	19	61	34
8	778	440	20	48	27

101. Mechanical Properties.—In purchasing copper wire in large quantities, certain requirements are made as to the strength and other mechanical properties of the wire. The strength of the various sizes of copper wire should be in accordance with Table 10. All wire should be fully up to the gauge standard and truly cylindrical. The inspector should test the size and roundness of the wire by measuring each end of each coil, and also several intermediate points. A variation of not more than 1½ mils on either side of the specified gauge number should be allowed, and there should not be a variation of more than 1 mil upon opposite diameters at the same point. A sample slightly over 12 inches long should be tested for torsion. This test may be made as follows: The wire is gripped by two vises exactly 12 inches apart. One of the vises should then be slowly revolved, and the number of twists before the rupture of the wire takes place should be counted.

Some telephone companies specify that hard-drawn copper wire shall stand the number of twists given below.

Diameter in Mils.	Twists in 6 Inches.
165.0	30
104.0	40
101.9	40
80.0	44
64.0	47

These are the sizes in general use for telephone-line wires.

102. Durability of Copper Wire.—Aside from its superior conductivity, copper wire possesses another great advantage over iron wire in that it is practically indestructible under ordinary climatic conditions. When the wire is first put up, a thin oxide rapidly forms upon its surface, after which no change whatever takes place. Except in very unusual conditions, where the atmosphere is filled with particularly destructive gases, copper wire will suffer no chemical change even when exposed to the weather for an indefinite time.

IRON WIRE.

103. Iron wire is largely used for telephone and telegraph lines, although it is rapidly being replaced by copper. It weighs 483 pounds per cubic foot and has a specific gravity of 7.73. A cubic inch weighs 0.28 pound.

104. The approximate value of the resistance per mile of a good quality of iron wire may be determined from the formula

$$R = \frac{360{,}000}{d^2}, \qquad (4.)$$

where d is the diameter of the wire in mils. For galvanized-steel wire, which is often used in place of iron wire, Roebling gives the following formula:

$$R = \frac{467{,}000}{d^2}. \qquad (5.)$$

The constant from which the resistance of galvanized-iron wire is calculated varies considerably. Roebling gives the following values for the constants for E. B. B. and B. B. grades of galvanized-iron wire:

$$R \text{ for E. B. B.} = \frac{338{,}000}{d^2}. \qquad (6.)$$

$$R \text{ for B. B.} = \frac{396{,}000}{d^2}. \qquad (7.)$$

Washburn & Moen give for the constants in formulas **5**, **6**, and **7** for their wire the values 462,000, 355,000, and 440,000, respectively.

The weight per mile of galvanized iron and steel wire may be calculated from the following formulas:

$$W \text{ for galvanized iron} = d^2 \times .0139, \qquad (8.)$$

$$W \text{ for galvanized steel} = d^2 \times .0140, \qquad (9.)$$

where d is the diameter in mils.

Washburn & Moen give .01408 for E. B. B., B. B., and steel, for the value of the constant for calculating the weight as in formulas **8** and **9**.

105. Galvanizing.—Iron, as is well known, is very susceptible to corrosion, due to moisture and other elements in the atmosphere, and in order to protect iron wires used in outdoor work, they are covered with a thin film of zinc. This process is called galvanizing. In order to render the surface of the iron wire perfectly clean, it is drawn through a vat of hydrochloric acid while hot, and immediately afterwards through a vat of molten zinc, the latter being kept at a uniform temperature of 740° F. by a furnace underneath the containing vessel.

The zinc coating, upon being exposed to the atmosphere, becomes oxidized, and as oxide of zinc is not soluble in water, it forms a protection against moisture. However, when the zinc is exposed to the action of sulphur or chlorine from salt spray or the acid gases in smoke, it is converted into zinc chloride or sulphate, which readily dissolves in water. Under especially adverse conditions, it is impossible to make iron wire last more than a few years, and in some cases a few months, and it is therefore desirable to use copper wire in such cases, as this is practically indestructible.

106. Grades of Iron Wire.—The various grades of iron wire on the market are termed "Extra Best Best," "Best Best," and "Best." A steel wire is also used which is cheaper and of higher resistance than iron. It has an advantage, however, of possessing greater tensile strength. It should not be used except on short lines, or in special cases where it is desirable to have great tensile strength.

107. The terms designating the grades are used almost indiscriminately, but among conscientious manufacturers they have approximately the following weights per mile-ohm:

		Washburn & Moen.
Extra Best Best	4,700	5,000
Best Best	5,500	6,200
Best	6,000	....
Steel	6,500	6,500

Extra Best Best (E. B. B.) is the highest grade iron wire obtainable. As may be seen from the value of the mile-ohm, it stands the highest in conductivity, and besides this, is very uniform in quality, being both tough and pliable.

Best Best (B. B.) is less uniform and tough than the Extra Best Best, but is a fairly good grade of wire. It is often sold, however, by the less reliable manufacturers, as the finest grade.

Best (B.) is a term applied to the poorest grades of wire. It is harder than the better grades, is much more brittle, and has a lower conductivity.

Steel wire is lower in conductivity than any of the grades of iron wire, but possesses a distinct advantage in point of tensile strength. For short telephone-lines where long spans are necessary, this wire is often used in preference to iron wire, as its lack of conductivity is not a great objection in short lines, while its tensile strength is a decided advantage.

108. Test of Galvanizing.—In view of the fact that the film of zinc is often so thin or so uneven as not to be effective in producing the desired results, it is always an important matter to test the galvanizing before accepting any large quantity of wire. For this purpose, several samples of the wire should be taken at random and immersed in a saturated solution of copper sulphate for one minute. They should then be wiped dry and clean, and the operation repeated four times. If at the end of the fourth immersion there is no appearance of a copper deposit on the wire, the wire remaining *black*, as after the first immersion, the sample is well galvanized. If, however, a deposit of copper does appear on the wire, it is a sign that the zinc has been entirely removed, by combining with the sulphuric acid of the solution to form zinc sulphate. In this case the wire should be rejected, as it shows that the zinc coating is not thick enough.

109. Table 11 gives the sizes and principal properties of three grades of galvanized-iron wire. The sizes are according to the Birmingham Wire Gauge, which is most commonly used in connection with iron wire.

TABLE 11.

IRON WIRE—BIRMINGHAM WIRE GAUGE.

Number B. W. G.	Diameter in Mils = d.	Area in Circular Mils = d^2.	Weight in Pounds.		Breaking Strengths in Pounds.		Resistance per Mile (International Ohms) at 68° F.		
			1,000 Feet.	One Mile.	Iron.	Steel.	E. B. B.	B. B.	Steel.
0	340	115,600	304.0	1,607	4,821	9,079	2.93	3.42	4.05
1	300	90,000	237.0	1,251	3,753	7,068	3.76	4.40	5.20
2	284	80,656	212.0	1,121	3,363	6,335	4.19	4.91	5.80
3	259	67,081	177.0	932	2,796	5,268	5.04	5.90	6.97
4	238	56,644	149.0	787	2,361	4,449	5.97	6.99	8.26
5	220	48,400	127.0	673	2,019	3,801	6.99	8.18	9.66
6	203	41,209	109.0	573	1,719	3,237	8.21	9.60	11.35
7	180	32,400	85.0	450	1,350	2,545	10.44	12.21	14.43
8	165	27,225	72.0	378	1,134	2,138	12.42	14.53	17.18
9	148	21,904	58.0	305	915	1,720	15.44	18.06	21.35
10	134	17,956	47.0	250	750	1,410	18.83	22.04	26.04
11	120	14,400	38.0	200	600	1,131	23.48	27.48	32.47
12	109	11,881	31.0	165	495	933	28.46	33.30	39.36
13	95	9,025	24.0	125	375	709	37.47	43.85	51.82
14	83	6,889	18.0	96	288	541	49.08	57.44	67.88
15	72	5,184	13.7	72	216	407	65.23	76.33	90.21
16	65	4,225	11.1	59	177	332	80.03	93.66	110.70
17	58	3,364	8.9	47	141	264	100.50	120.40	139.00
18	49	2,401	6.3	33	99	189	140.80	164.80	194.80

110. Table 12 contains the results of tests of certain samples of wire of American manufacture. The column headed "Percentage Conductivity" gives the percentages which the conductivities of the various samples bear to the conductivity of pure copper. "Percentage of Elongation" means the percentage of the length a wire will elongate before breaking. The column headed "Relative Breaking Stress" gives the number of feet of its own length that each sample would be able to sustain.

TABLE 12.

Sample Mark and B. W. Gauge.	Mechanical.					Electrical.	
	Weight per Mile, in Pounds.	Percentage of Elongation.	Number of Twists that 6 in. Will Stand.	Actual Breaking Stress, in Pounds.	Relative Breaking Stress.	Percentage Conductivity.	Resistance per Mile in Ohms, at 60° F.
E. B. B. 12	190.83	11.50	15.00	417.50	11,552.20	14.40	30.50
E. B. B. 8	381.66	17.70	26.50	937.50	12,930.50	17.30	12.67
E. B. B. 11	222.64	17.20	21.50	577.50	13,639.40	15.60	24.20
151 9¼	282.80	10.00	26.50	770.00	14,375.90	21.90	16.10
E. B. B. 10	254.44	17.70	28.50	697.50	14,478.10	17.80	18.42
146 9¼	287.50	16.00	29.00	832.50	15,288.86	21.90	16.10
E. B. B. 6	508.88	11.40	21.50	1,587.50	16,462.40	17.70	9.21
E. B. B. 9	318.05	19.30	17.50	1,007.50	16,725.10	16.90	15.54
Nashua 8	381.66	15.10	26.50	1,535.00	21,183.00	14.70	15.00
M. S. plain 6	528.00	10.40	19.50	2,137.50	21,375.00	13.50	11.78
443 8	378.10	10.00	31.00	1,635.00	22,301.40	16.50	16.10
A. H. 9¼	293.50	16.00	27.50	1,257.50	22,635.00	15.10	22.70

111. The wires for use on telegraph and telephone lines should be capable of elongating at least 15 per cent. before breaking, and the breaking stress should not be less than two and one-half times its weight per mile. It should also be able to bear not less than 15 complete twists in a length of 6 inches without breaking. By referring to Tables 11 and 12, it will be seen that the wires which bear the greatest tensile strain have the poorest conductivity.

MERITS OF COPPER AND IRON WIRES.

112. Iron wire possesses an advantage over copper wire in respect to its first cost, it being much cheaper; but in nearly all other respects, copper is very much superior. In tensile strength there is little to choose between them, hard-drawn copper being plenty strong enough for all except the most trying conditions. In durability, copper is far superior, for no matter how well the galvanization of iron wire is done, the zinc coating will eventually allow the corrosion of the iron itself, after which the destruction of the wire is a matter of but a short time. The greatest points in favor of copper, however, are its electrical properties. It has a conductivity six times better than the best grades of iron wire, and over seven times better than the poorer grades.

113. We have seen that the distance over which telephonic transmission can be accomplished depends in some manner upon the product of the ohmic resistance of the line and the electrostatic capacity. If either one or both of these properties are increased, telephonic transmission will be correspondingly poorer. If an iron wire of the same size as a copper wire is used, the electrostatic capacity of the circuit will be practically the same, but the resistance will be six or seven times higher, and therefore the product of electrostatic capacity and the resistance will be from six to seven times higher. Manifestly, this is a great drawback to the use of iron. If we use an iron wire having the same conductivity as a given copper wire, the iron wire must possess six or seven times as great a cross-sectional area as the copper, and in this case the electrostatic capacity would be much higher, thus increasing the product of the capacity and resistance. These facts alone absolutely prohibit the use of iron wire on very long telephone-lines.

114. Again, iron is the most magnetic substance known, while copper is non-magnetic. This renders the inductance of iron circuits considerably higher than that of copper, thus producing another strong advantage in favor of copper.

ALUMINUM FOR TELEPHONE CIRCUITS.

115. The adaptability of aluminum as a line conductor for telephone and telegraph currents is exciting more and more interest as the price of aluminum is lowered, on account of the improvements in its methods of production. The following table gives some figures regarding the relative merits of aluminum and copper.

COMPARISON OF PROPERTIES OF COPPER AND ALUMINUM.

	Aluminum.	Copper.
Conductivity (for equal sizes).............	.54 to .63	1.
Weight (for equal sizes)....................	.33	1.
Weight (for equal length and resistance)....	.48	1.
Price—Al. 29c.; Cop. 16c. (bare line-wire)...	1.81	1.
Price—(Equal resistance and length, bare line-wire)................................	.868	1.
Temperature coefficient per degree F.......	.002138	.002155
Resistance of mil-foot (20° C.)..............	18.73	10.5
Specific gravity............................	2.5 to 2.68	8.89 to 8.93
Breaking strength (equal sizes).............	1.	1.

116. This table shows that copper has a decided advantage in regard to resistance for equal sizes, but aluminum has a great advantage in the matter of weight, an aluminum wire being less than one-third as heavy as a copper wire of the same size. An aluminum wire possesses less than one-half the weight of a copper wire having the same length and resistance, although, of course, in this case the aluminum wire would be considerably larger than the copper. Pound for pound, aluminum at the prevailing price of 29 cents is almost twice as expensive as copper at 16 cents, but for two wires of equal resistance and length, the aluminum wire will be over 13 per cent. cheaper than the copper. For equal sizes, the strength of aluminum and copper will be about equal, but for equal resistances, the aluminum wire will have a considerable advantage in point of strength as well as of cost.

The grades of aluminum wire in Table 13 are those manufactured by the Pittsburg Reduction Company. It is best to use an annealed wire made purposely for tying the line-wire to the insulators, because an aluminum line-wire tied with too hard

TABLE 13.

RESISTANCE, TENSILE STRENGTH, AND WEIGHT OF ALUMINUM TELEPHONE-WIRE.

Grade.	Conductivity. Pure Copper = 100.	Comparative Section of Equal Conductivity. Copper = 100.	Comparative Weight of Same Lengths of Equal Conductivity. Copper = 100.
A 0	62	156.4	47.
A 75	58	167.0	50.2
A 2	54	180.0	54.

No. in B. & S. Gauge.	Diameter in Mils. d.	Circular Mils. d^2.	Area in Square Inches. $\frac{d^2 \times .7854}{1,000,000}$	Grade A 0. Resistance per 1,000 Feet at 75° F.	Grade A 0. Tensile Strength, Pounds per Square Inch.	Grade A 75. Resistance per 1,000 Feet at 75° F.	Grade A 75. Tensile Strength, Pounds per Square Inch.	Grade A 2. Resistance per 1,000 Feet at 75° F.	Grade A 2. Tensile Strength, Pounds per Square Inch.	Pounds per Mile. Sp. Gr. 2.68. Water, 62.355 lb. per Cu. Ft.	Pounds per Mile of Aluminum Having Same Resistance as Copper Wire of Size Given. Grade A 75.
4	204.31	41,742.0	.0327840	.4012	27,000	.4288	33,000	.4605	40,000	200.90	336.0
5	181.94	33,102.0	.0259980	.5058	27,500	.5408	34,000	.5818	42,000	159.30	266.4
6	162.02	26,250.5	.0206170	.6380	28,000	.6820	35,000	.7325	44,000	126.35	211.4
7	144.28	20,816.0	.0163490	.8044	29,000	.8600	36,000	.9235	46,000	100.21	167.6
8	128.49	16,509.0	.0129660	1.6340	30,000	1.1050	37,000	1.1870	48,000	79.46	133.2
9	114.43	13,094.0	.0102840	1.2780	32,000	1.3670	39,000	1.4680	50,000	62.99	105.4
10	101.89	10,381.0	.0081532	1.6130	33,000	1.7240	40,000	1.8520	51,000	48.71	83.6
11	90.74	8,234.0	.0064670	2.0330	35,000	2.1730	41,000	2.3350	53,000	39.63	66.3
12	80.81	6,529.9	.0051286	2.5650	39,000	2.7410	42,000	3.0840	55,000	31.43	52.6
13	71.96	5,178.4	.0040671	3.2330	.....	3.4560	.....	3.7120	.....	24.83	.....
14	64.08	4,106.8	.0031469	4.1790	.....	4.4670	.....	4.7980	.....	19.76	.....

a wire will become dented, and consequently will break with less strain than if the cross-section had been unimpaired. McIntire sleeves of aluminum are made for making joints in the line-wire.

117. Mr. C. T. Child states that the conductivity of aluminum is 63 per cent. of that of copper, referring to commercial samples. This would make the diameters of wires for equal conductivity as follows: copper 10, aluminum 12.64. Two wires of equal conductivity would require 1 pound of aluminum and 2.08 pounds of copper.

Based on the weights for equal conductivity (copper 100, aluminum 48), there is an equivalent price of aluminum at which conductors of equal efficiency made from the two metals will be equal in cost. These relative prices are here given in cents per pound.

Price of Copper.	Equivalent Price of Aluminum.
12	25.
13	27.1
14	29.15
15	31.2
16	33.3
17	35.35
18	37.35
19	39.4
20	41.5

If two wires of equal length and equal resistance, one of copper and the other of aluminum, be covered with the same thickness of insulating material, the amount required by the aluminum will be 17½ per cent. more than that required by the copper. The weight of the insulated aluminum, if the ordinary rubber or other good insulating material be used, will still be considerably less than that of the insulated copper wire.

The tensile strength of commercial soft-drawn and hard-drawn aluminum wire is given by Child as 26,000 and 40,000 pounds per square inch, respectively. Since the aluminum wire for the same conductivity will have a larger cross-section, then for equivalent wires the aluminum is the stronger.

Both aluminum and copper are practically indestructible under ordinary atmospheric exposure, and there would probably be but little choice between them in this regard. In bare-wire construction, however, the fact that aluminum is somewhat more bulky for a given resistance would be of little disadvantage from a mechanical standpoint, except for its greater resistance to the wind, while it would possess an advantage in regard to strength, cost, and weight. From an electrical standpoint, however, there is one disadvantage, due to the greater size of aluminum wire, which is especially significant in telephone work. Its greater surface for a given conductivity renders its electrical capacity with respect to the earth or with respect to other conductors much higher, and thus the product of the electrostatic capacity and the resistance would be considerably greater than for a copper wire of the same resistance.

STRINGING OF WIRES.

118. Paying Out.—Where but a single wire is to be strung upon poles, the method usually adopted is to secure one end to the cross-arm of the pole at the beginning of the stretch and to unreel the wire from a pay-out reel carried along the base of the poles. The wire is drawn up to each cross-arm, and after being pulled up to the proper tension, is tied to the insulators, as will be described later. For paying out the wire, many different forms of reels may be procured. A form mounted on a hand-barrow is shown in Fig. 52, and is one of the most convenient types of reel. The coil of wire is held in place by the four vertical pins on the reel itself, and as the barrow is carried along by two men, the wire is paid out without any danger of kinking.

When it is desired to pay out several wires at once, as described later, a number of reels of the same general form

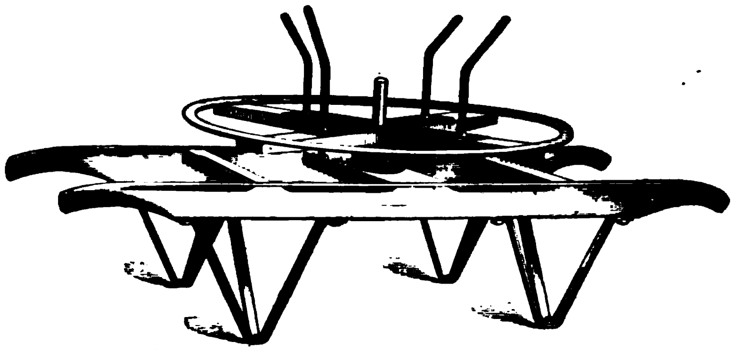


FIG. 52.

as that of Fig. 52 are mounted upon a wagon or cart, which is then drawn along the pole line, paying out a separate wire from each reel.

When, however, more than a few wires are to be strung, what is termed a running board is used. This consists of a piece of oak board about as long as a cross-arm and having holes for the attachment of wires spaced about the same distance apart as the pins on a cross-arm. A rope is attached to the center of the running board, by which it may be drawn over the cross-arms, pulling the wires after it.

When the running board is used, a strong rope is first laid over all the cross-arms of the stretch to be strung. The pay-out reels are mounted at the beginning of the stretch, and the wires from them are attached directly to the running board, to the center of which is also attached the rope. By means of a team of horses at the other end of the stretch, the running board is then drawn along, being lifted over the pole tops by men stationed on each pole. In this way 10 wires may be strung at once. When the wires for the lower cross-arms are to be strung, the running board is usually made to carry 5 wires instead of 10, so as to serve for one end of the cross-arm only. Sometimes, however, two of these are used at once, one on each side of the pole, a separate rope being used for each.

After the wires are properly laid upon the cross-arm, one end of each is made fast and then each wire is pulled up to the proper tension.

119. Tension of Wires.—Several methods are in vogue for obtaining the proper tension in the line-wire. The wire is clamped by means of some form of wire clamp, or "come-along," as they are usually termed, of which there are many forms on the market. It is then pulled up either by hand or by means of a block and tackle, the tension being judged either by the amount of sag in the wires or by a line dynamometer, or spring balance, which shows by an indicator the number of pounds of tension in the wire.

120. In Fig. 53 is shown a form of come-along which has met with much favor. It has the advantage of having

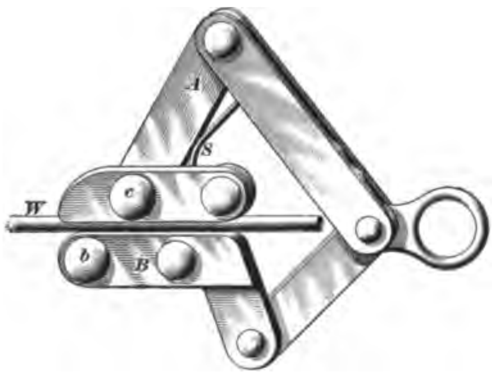


FIG. 53.

smooth, straight parallel jaws, thus obtaining a firm grip on the wire without the liability of kinking or nicking it. These clamps are made of steel forgings riveted together as shown. The member *A* is pivoted to the jaw *B* by the rivet *b*, and to the other jaw by the rivet *c*, so that when the wire *W* is placed between the jaws and tension applied on the eyelet of the come-along, the jaws are forced together, thus gripping the wire and at the same time maintaining the pull in the direction of the wire. The spring *S* serves to open the jaws automatically, thus releasing the wire as soon as the tension is removed.

Considerable care must be taken not to nick or kink hard-drawn copper wire. When a kink does occur, it should be cut out and the wire joined.

121. Table 14, taken from Roebling's handbook on wire, gives the amount of sag in inches at the center of the span for different lengths of span at various temperatures.

TABLE 14.

SAG IN LINE-WIRES.

Temperature in Degrees Fahrenheit.	Span in Feet.					
	75	100	115	130	150	200
	Sag in Inches.					
− 30	1	2	$2\frac{1}{2}$	$3\frac{3}{8}$	$4\frac{1}{2}$	8
− 10	$1\frac{1}{4}$	$2\frac{1}{2}$	3	$3\frac{3}{4}$	5	9
10	$1\frac{1}{2}$	$2\frac{5}{8}$	$3\frac{1}{2}$	$4\frac{3}{8}$	$5\frac{3}{4}$	$10\frac{1}{4}$
30	$1\frac{3}{4}$	3	4	$5\frac{1}{8}$	$6\frac{3}{4}$	12
60	$2\frac{1}{2}$	$4\frac{1}{4}$	$5\frac{1}{2}$	7	9	$15\frac{3}{8}$
80	$3\frac{1}{8}$	$5\frac{3}{8}$	7	$8\frac{5}{8}$	$11\frac{1}{4}$	$18\frac{3}{4}$
100	$4\frac{3}{8}$	7	9	11	14	$22\frac{1}{4}$

Obviously, the temperature at the time of stringing plays an important part in the determination of the proper tension, for if strung too tight in hot weather, the wires, in contracting in colder weather, will be likely to snap. Therefore it is necessary to allow a much greater sag in hot weather than in cold. For spans from 400 to 600 feet in length, the sag should be about $\frac{1}{40}$ of the length of the span, while for spans of from 600 to 1,000 feet in length, the sag should be about $\frac{1}{30}$ of the span.

122. Tying.—There are several methods of tying line-wires to insulators, but the one shown in Fig. 54 is the most common. This view shows both plan and side view of the insulator and tie. The tie-wire for an ordinary line insulator is usually made from 14 to 16 inches in length and of the same size as the line-wire, or slightly smaller. The line-wire is laid in the groove of the insulator, after which the two ends of the tie-wire, after passing half around the insulator, are wrapped in a close spiral about the line-wire. Some advocate to start wrapping one end of the tie-wire over and the other end under the line-wire.

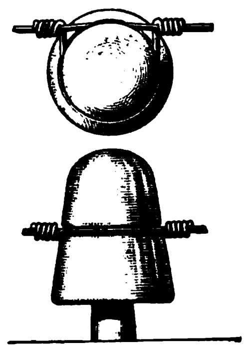


FIG. 54.

123. Another tie, and one which is now largely being used in telephone work, and which is better than the one just described, is shown in Fig. 55. In this, the line-wire is laid in the groove of the insulator and the tie-wire is laid in the groove and passed once entirely around the insulator. One end of the tie-wire is then brought *down over* the line-wire, while the other end is brought *up under* it in an opposite direction, the two ends being wound around the line-wire, as shown in the figure. On straight-away work, the line-

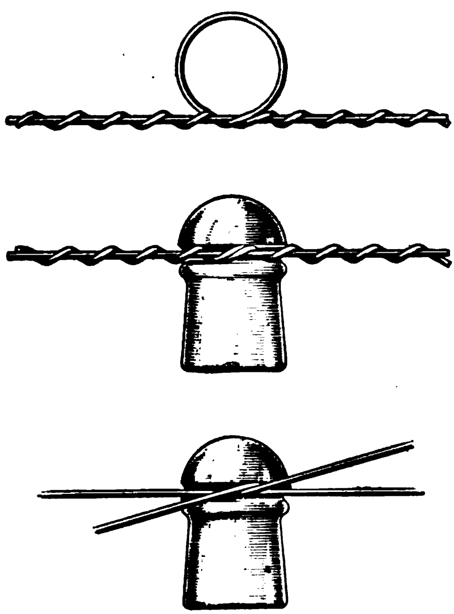


FIG. 55.

wire should always lie on the side of the insulator next to the pole, excepting the two inner wires, which are placed on the side away from the pole. On curves, however, all the line-wires should always lie on the side away from the center of the curve, in order that the strain, due to the bend in the wire, may be taken by the insulator instead of by the tie-wire.

124. Splicing.—Until recent years, wires were usually connected in this country by means of the American wire

FIG. 56.

joint, shown in Fig. 56. In order to make this joint, the wires are first placed side by side, and then each end is wound about the other. The joint should then be soldered, to insure the maintenance of perfect electrical contact. In soldering this joint, it is well to apply solder only at its center, for the reason that the heat necessary to cause the solder to flow takes a certain amount of temper from the wire, and therefore is very apt to weaken it. By weakening the center portion only, two strands of the wire are available to stand the strain, and therefore a rupture is not as likely to occur as if the ends of the splice were heated, for then the strain would be borne by a single strand only.

125. Another joint, which is rapidly coming into general use, and which should entirely supersede the American joint, is the McIntire sleeve joint. Since no soldering is required, there is not the danger of injuring the strength

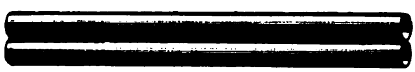


FIG. 57.

of the line-wire by heating. The ends of the wire are slipped into a double sleeve of copper or iron, as shown in

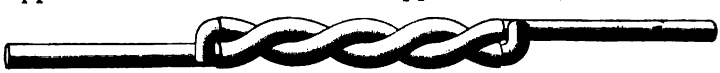


FIG. 58.

Fig. 57, and the two are then twisted through several turns.

making a joint, as in Fig. 58. These joints give excellent service, always keeping good electrical contact without the use of solder. Three complete turns should always be given, and the ends, although not so shown, should be turned out.

126. Transpositions.—The theory of transpositions in telephone-lines has already been given. The usual method of making transpositions is shown in Fig. 13. For making transpositions in this manner, a special double-groove insulator should be used. These may be purchased under the name of transposition insulators, and form the most effective way of accomplishing what is otherwise a rather awkward piece of work. Sometimes a double cross-arm is used, as shown in Fig. 14, one arm being placed on each side of the poles on which transpositions are made. This forms a convenient method, the cross-over connection being easily made, but the extra cross-arms and insulators render this construction more expensive.

127. Climbing.—Two forms of climbers, shown in Figs. 59 and 60, are in common use. These are termed, respectively, "Western" and "Eastern" climbers, and each style has its own advocates. In the Western climbers, the rod which is strapped to the leg is on the opposite side from the spur, and therefore is secured to the outside of the leg. In the Eastern pattern, the rod is on the same side as the spur, and is therefore secured to the inside of the leg.

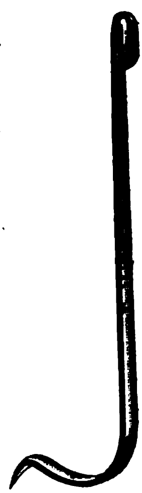


FIG. 59.

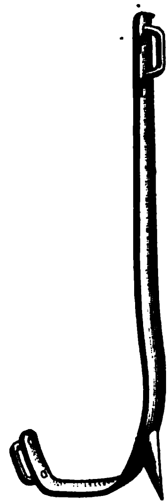


FIG. 60.

Climbing is an art which can only be attained by practice, and the best way to learn it is to practice on the lower portion of a pole, without attempting to ascend to the top at first. The main points to be remembered in climbing are to secure a hold with the spur by a direct downward thrust of the leg, instead of with a side thrust towards the pole, as is the tendency with an amateur; also, the body should be held out at arm's length from the pole, the pole being clasped in the palms of the hand, instead of being hugged close to the body. It is more difficult to descend than to ascend, and therefore the beginner should be cautious about climbing too high at first.

TELEPHONE CABLES.

128. Where it is necessary to run a greater number of wires than can be accommodated by the bare-wire construction already described, the use of cables becomes necessary. For both indoor and outdoor work, the cable makes it possible to easily run a large number of wires where the same number by the ordinary construction would be out of the question. Moreover, for the problem of underground and underwater work, where it is impossible to use bare-wire construction, the cable forms the only solution. In the early forms of cables used with the ground-return system, much trouble was experienced, due to the induction or cross-talk between the separate wires. It is easily seen that the same inductive actions which give so much trouble on bare-wire construction will be much more effective in producing trouble in cables, where the wires are so much closer together. Many forms of anti-inductive devices were tried, some with more or less success, but the total elimination of cross-talk in cables carrying grounded circuits has so far not been accomplished.

129. The best remedy, and in fact the only one, is to use complete metallic circuits in a cable, twisting the two wires of each circuit together, thus virtually accomplishing a transposition every few inches. Cables carrying as many as 240 wires, or 120 circuits, can be made with a cross-sectional area less than that of a circle 3 inches in diameter without the slightest tendency to cross-talk, this being accomplished by twisting the wires of the various pairs together.

RUBBER-COVERED CABLES.

130. Cables composed of rubber-covered wire are frequently used in special cases, although for general telephone work, the paper-insulated cable is much more desirable. A good rubber-covered cable manufactured in this country is made as follows: The wires are of copper No. 16 or 18 B. & S. gauge, having a conductivity of 98 per cent. of that of pure copper. The wire is thoroughly tinned and then given a double coating of rubber insulation and a final coating of tape, and twisted in pairs. After the requisite number of pairs are bunched, the cable is double taped and covered with tarred jute, over which is placed a heavy braid of cotton saturated with weather-proof compound, which serves not only to protect the rubber from the action of the air, but to protect the entire cable from mechanical injury. The sizes and weights of cables made in this manner are given in Table 15.

TABLE 15.

AERIAL CABLE RUBBER-COVERED WIRES.

Number of Pairs.	Number of Conductors.	Diameter, Inches.	Weight per 1,000 Feet, Pounds.
3	6	$\frac{9}{16}$	175
5	10	$\frac{11}{16}$	256
10	20	$\frac{29}{32}$	452
15	30	1	633
20	40	$1\frac{1}{8}$	813
25	50	$1\frac{1}{4}$	994

131. The insulation resistance of wires in this cable will, if the cable is in good condition and the proper materials used, vary from 300 to 500 megohms per mile, at a temperature of 60° F., after the cable has been immersed in water for 24 hours. This cable is, therefore, well adapted for underwater work where it is not subject to mechanical injury. For use in mines, or where it is necessary to pass a large number of wires on poles through the foliage of trees, this cable should give good results, but should never be used in very long lengths. The great objection to cables of this kind is the high electrostatic capacity of the conductors. Rubber is an excellent insulator, but has a very high specific inductive capacity, thus greatly increasing the electrostatic capacity of the wires which it serves to insulate.

PAPER CABLES.

132. Methods of Reducing Capacity.—To reduce the electrostatic capacity of the conductors of a cable, three methods are available: First, the wires may be placed farther apart; second, the wires may be made smaller; and third, an insulating medium having a low specific inductive capacity may be used.

To place the wires farther apart would be to defeat the principal object for which the cable is employed—that is, compactness. The sizes of the wire may be reduced to a certain limit, but beyond that limit the mechanical strength of the conductor and its ohmic resistance forbids us to go. As a result of this reduction in the size of wires, Nos. 19 to 22 B. & S. gauge are commonly used. In following the third method of reducing the electrostatic capacity, various materials having a lower specific inductive capacity than rubber have been tried, and have been found to give far better results so far as the electrostatic capacity is concerned, and, in fact, in all other respects, when proper care was exercised in their manufacture and maintenance.

133. Dry-Core Cables.—The telephone cables now most commonly used in this country are made by insulating the various wires with a loose wrapping of very porous dry paper, after which the wires are twisted in pairs and bunched into a cable. A sheath of lead is then placed over the cable in order to exclude all moisture and also to prevent mechanical injury. At first liquefied paraffin was forced into these cables, it being impregnated with carbonic-acid gas. The comparatively low specific inductive capacity of the paraffin was rendered still lower by the carbonic-acid gas, and a marked reduction in the electrostatic capacity of the cable was thus obtained, while the insulation resistance was very high. It was afterwards found to be unnecessary to impregnate the paper insulation of the cable with paraffin, so long as means could be provided for the absolute prevention of the entrance of moisture. The loose wrapping of the paper and its porous nature insure the inclusion of a great amount of dry air in the cable, which, as we have seen, possesses the lowest electrostatic capacity of any known substance, hydrogen excepted. Two or three feet at each end of the dry-core cable is always saturated or sealed up tight, to exclude moisture, with paraffin, or, better, with some of the special compounds such as made and used by the cable manufacturers. Immediately after testing in the factory, the lead sheath at each end is hermetically sealed by a plumber's joint.

134. The electrostatic capacity of the wires in a cable built in this manner is often as low as .06 microfarad per mile, and it is customary in making specifications for telephone cables using No. 19 B. & S. gauge wire to specify that the electrostatic capacity of each wire shall be lower than .08 microfarad per mile. All cables of this description are made in twisted pairs, the conductors being twisted together so as to give one turn in about 6 inches.

The dry-core cable represents the highest development in the line of telephone cables. The high insulation obtained by the dry air and paper, the low electrostatic capacity, and the compactness of the cable as a whole render it admirably adapted for both underground and aerial work, but it is not suited, nor is any other form of cable, to long-distance telephone transmission, the production of the long-distance cable being now probably the greatest unsolved problem before the telephone engineer.

135. Felten-Guilleaume Cables. — The dry-core cables manufactured by this company differ from the construction of the dry-core cables already described only in the method of insulating the two wires of a pair from each other and the pairs from other pairs. The two wires are arranged on each side of a strip of paper, after which the wires are twisted together as shown in Fig. 61. After this,

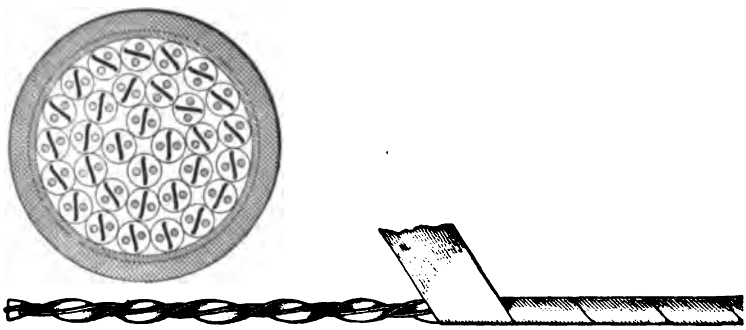


FIG. 61.

a ribbon of paper is wound about the pair, thus enclosing it in a continuous tube of paper. These tubes are then bunched together and enclosed in a lead sheath, as shown in the upper portion of Fig. 61. Cables made in this manner have shown a specific inductive capacity as low as .05 microfarad per mile.

136. Objections to Dry-Core Cables.—One objection is often urged against the dry-core cable, and whether or not this is a serious objection depends upon the manner of manufacture and the subsequent care of the cable. A puncture in the sheath allows the entrance of moisture, which, due to capillary attraction, will soon penetrate the entire length of the cable, thus totally ruining the insulation.

When moisture first enters, immediate steps must be taken to expel it and to repair the fault, and if this is not done in an intelligent and prompt manner, the cable will soon be worthless. This point shows the necessity for making frequent insulation tests on cables of the dry-core type, so that if moisture enters, its presence may be detected before it has time to do serious damage. Of this more will be said later.

137. In England and in France some dry-core cables have been laid with provision for forcing dry air through the cable at a pressure of about 15 pounds per square inch without disturbing the cable at all. Should moisture from any cause get into the cable, it may be expelled by blowing the dry air through it, the looseness with which the insulating material is packed allowing this to be done. The air is thoroughly dried by passing it through a series of U-tubes containing calcium chloride, and then it is filtered by passing it through dry cotton wool. The expulsion of the moisture may be aided by warming the cable, if it is known to be wet at any particular place.

138. Saturated-Core Cables. — Paper-insulated cables are now often saturated with certain insulating compounds, in order to maintain the insulation even when the sheath is punctured. These cables are commonly termed saturated-core cables, in order to distinguish them from the dry-core. For short lengths in small exchanges, where the requisite means for testing out and repairing cables are not at hand, the saturated-core cable is probably the most advantageous. It should, however, never be used on long-distance work or on circuits which are likely to be connected with very long lines.

139. Lead Sheaths for Cables. — Sometimes the sheaths for cables are made of pure lead, but specifications usually call for a mixture of 3 per cent. of tin with the lead. The reason for this is that where cables are used for underground work, the lead is more likely to be attacked by chemical action than is the mixture of lead and tin. Considerable difference of opinion exists as to the advisability of making the mixture of lead and tin, some manufacturers claiming that it is impossible to obtain an even mixture of the two, and that the sheath will not be homogeneous, and will therefore contain spots that are more or less brittle, owing to the excess of tin.

The Standard Underground Cable Company, of Pittsburg, make the sheath of pure lead and afterwards give it an outside coating of tin, claiming that the tin is then in a position to do the most good in preventing chemical action without in any way interfering with the quality of the sheath itself.

140. Outside Braiding of Cables.—The lead sheath of telephone cables is frequently covered with a braiding of cotton saturated with weather-proof compound. While this undoubtedly protects the sheath from abrasion in both overhead and underground work, it is subject to several disadvantages. Among these is the fact that it renders the location of punctures or injuries in the cable sheath more difficult to locate. After some years, the braiding rots off and hangs in shreds from the aerial cables, thus presenting an unsightly appearance. In underground cables, the braiding is likely to become disengaged, and thus bind the cable in the duct in which it lies, thus rendering its subsequent drawing out a very difficult matter. The general opinion now among many engineers seems to be that, except under certain conditions, the outside braiding on a telephone cable is a disadvantage, and, therefore, that its extra expense is worse than useless.

SPECIFICATIONS FOR TELEPHONE CABLES.

141. The following specifications are taken from the printed matter of a prominent manufacturer of cables and the specifications of the American Bell Telephone Company:

142. Conductors. — Each conductor shall be .03589 inch in diameter (19 B. & S.) and have a conductivity of 98 per cent. of that of pure soft copper.

143. Core.—The conductor shall be insulated, twisted in pairs, the length of the twist not to exceed three inches, and formed into a core arranged in reverse layers. At least two feet at each end of a cable and at least two feet on each side of a joint shall be saturated with an insulating material—in the latter case, of course, after the joint has been made.

144. Sheath.—The core shall be enclosed in a pipe composed of lead and tin; the amount of the tin shall not be less than 3 per cent. The pipe shall be formed around the core, have a thickness of not less than one-eighth ($\frac{1}{8}$) of an inch, and shall be free from holes or other defects, and of uniform thickness and composition.

145. Electrostatic Capacity.—The average electrostatic capacity shall not exceed .08 of a microfarad per mile, each wire being measured against all the rest and the sheath grounded; the electrostatic capacity of any wires so measured shall not exceed .085 of a microfarad per mile. These figures apply only to the paper cable, and proper allowance shall be made for the rubber-covered wire used at the terminals.

146. Insulation Resistance.—Each wire shall show an insulation of not less than 500 megohms per mile, at 60° F., when laid, spliced, and connected to terminals ready for use, each wire being measured against all the rest and the sheath grounded.

147. Conductor Resistance.—Each conductor shall have a resistance of not more than 47 ohms, at 60° F., for each mile of cable, after the cable is laid and connected to the terminals. The Bell Companies specify that the resistance shall not exceed this amount after the cable has been laid, spliced, and connected to terminals.

148. The above specifications are practically identical with those issued by the Bell Companies. The following additional requirements and notes are, however, inserted in the Bell Companies' specifications:

The telephone company is to have the right to make such tests of the quality of the materials used and of the electrical properties of the finished cable as it may desire. The inspector of the telephone company is to have the power to reject the cables should the quality of the materials used or the electrical properties of the cables fall below the requirements specified.

The manufacturer shall guarantee that for one year from the time the cables are laid, spliced, and connected to terminals, the electrostatic capacity and the resistance of the conductors shall not have increased nor the insulation resistance of the conductors have decreased beyond the limits specified. The manufacturer, however, shall not be responsible for the failure of cables brought about by injuries to the sheath or conductors due to causes beyond his control.

The durability of a cable depends so largely upon the character of the joints that it is recommended that the utmost care be exercised in making splices and in drying the core before a joint is sealed.

The conductors of a pair in one cable length should be connected to the conductors of a pair in the next cable length, and at each splice the relative position of the pairs in the cable should preferably be changed.

The tests for insulation resistance may be made with an electromotive force not exceeding 550 volts. As a measure of safety, when more than 200 volts are employed in such tests, a resistance of 100,000 ohms should be included in the circuit with the source of the electromotive force and the conductors of the cable.

The specifications for the aerial cable are the same as the above, with the exception that the lead is to be $\frac{3}{32}$ inch instead of $\frac{1}{8}$ inch thick.

149. Table 16 gives the outside diameters and weight per thousand feet of cables containing from 1 pair to 100 pairs.

TABLE 16.

TELEPHONE CABLES.

Number Pairs.	Outside Diameter in Inches.	Weight per 1,000 ft. in Pounds.
1	$\frac{5}{16}$	214
2	$\frac{3}{8}$	302
3	$\frac{1}{2}$	515
4	$\frac{9}{16}$	629
5	$\frac{5}{8}$	747
6	$\frac{21}{32}$	877
7	$\frac{11}{16}$	912
10	$\frac{13}{16}$	1,214
12	$\frac{15}{16}$	1,375
15	1	1,566
18	$1\frac{1}{16}$	1,758
20	$1\frac{1}{8}$	1,940
25	$1\frac{5}{16}$	2,332
30	$1\frac{7}{16}$	2,748
35	$1\frac{1}{2}$	2,985
40	$1\frac{9}{16}$	3,176
45	$1\frac{5}{8}$	3,365
50	$1\frac{3}{4}$	3,678
55	$1\frac{13}{16}$	3,867
60	$1\frac{7}{8}$	4,055
65	$1\frac{15}{16}$	4,241
70	2	4,430
80	$2\frac{1}{8}$	4,804
90	$2\frac{1}{4}$	5,180
100	$2\frac{3}{8}$	5,505

SPLICING AND REPAIRING CABLES.

150. The splicing together of two dry-core telephone cables is a matter involving the greatest amount of care and skill. It should never be left in the hands of irresponsible persons. If the cable is already on poles, it will be necessary to erect a platform, if one is not already provided, on the pole where the splice is to be made; or, if in the middle of a span, a traveling platform suspended beneath the cable from the messenger wire upon which the cable is supported must be used, provided, of course, arrangements can not be made to make the splice on the ground.

151. Testing for Moisture.—Careful tests should be made to determine whether or not moisture has entered the insulation of the cable from the exposed end. If the cable is new, its end will be sealed and probably will be free from moisture, but if the splice is necessary on account of having to cut away an injured portion of the cable, there are many chances that moisture will be present in the insulation. A short piece of cable should be cut off and dipped in boiling paraffin. The rising of bubbles through the liquid is a sure sign of moisture, but if no bubbles arise, then it is safe to say that the cable is dry. If moisture is found in small quantities, it may sometimes be expelled by heating the cable sheaths with a torch for a considerable distance back of where the splices are to be made and gradually working towards the end. Great care must be taken, however, in doing this, not to melt the lead and thus destroy the sheath. The cable should not be spliced until all moisture is expelled, and if this can not be done by ordinary methods, then a section of it should be cut away, and the end so exposed again tested for moisture.

152. Before beginning work on the splice itself, careful tests should be made for grounded or open wires in a cable, for to connect a good wire in one section of the cable to a defective wire in another section means the loss of both the good and the bad wire.

153. When all is ready, cut away the lead sheath for a space of from 6 to 12 inches from the end of each section, the distance depending upon the size of the cable. In order to prevent the paper from untwisting and exposing the wires, the ends of each cable should be dipped in hot paraffin, or the paraffin may be poured over the ends until the paper is saturated. Then slip a piece of lead pipe, slightly larger than the outside diameter of the cable and from 18 inches to 2 feet in length, over one end of the cable, and back several feet out of the way of the workmen. The condition of the cable would then be represented by Fig. 62. The wires

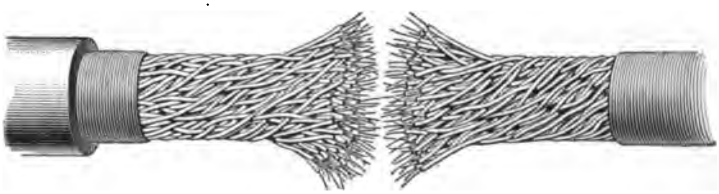


FIG. 62.

are in pairs, usually one wire of each pair being red and the other white. Now slip a paper sleeve (previously baked in a slow oven in order to expel all moisture) over each red wire in the end of one cable and over each white wire in the end of the other cable. The wires of the pairs are then joined by merely twisting them together, and the joint is bent away from the paper sleeve, as shown in Fig. 63. The

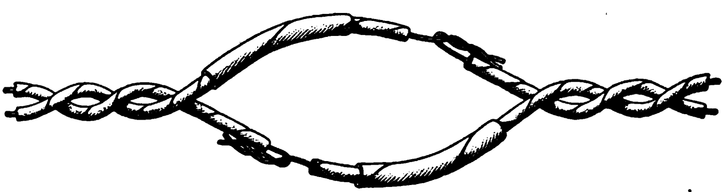


FIG. 63.

joint should then be soldered, using the grease of a tallow candle as a flux, after which the sleeves should be slid over the joints, leaving the finished splice of each pair as shown in Fig. 64. In making these splices, care must be taken not to spill solder over any of the other wires and to stagger the joints as much as possible throughout the entire length of a

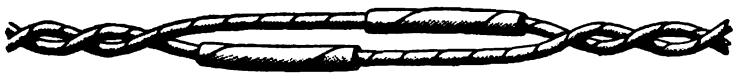


FIG. 64.

splice, in order that an undue bulge may not occur at any one section of the cable. When all the wires are spliced and smoothed down, the appearance of the cable will be somewhat as represented by Fig. 65.

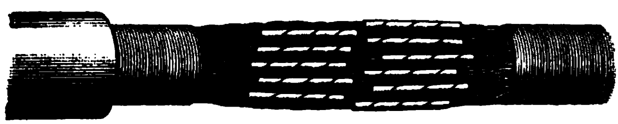


FIG. 65.

Some very reliable cable installing and manufacturing companies do not solder the copper conductors where joined together. Twisting the wires firmly together, putting a paper insulating sleeve over each conductor joint, and filling the whole cable joint with an insulating compound have proved sufficient, so they claim.

154. Boiling Out.—The next process is termed boiling out, and upon it depends in great measure the success of the splice. A large bowl of hot paraffin and a convenient ladle should be provided. The bowl should be placed directly under the splice and as close to it as possible, and the hot paraffin should be poured, by means of the ladle, over the splice and allowed to drip back into the bowl. This process should be repeated until no bubbles appear in the hot liquid, the presence of bubbles always indicating that a certain amount of moisture is left in the cable. After the splice is boiled out, it should be served with a plain strip of white cotton and again boiled out with paraffin. The lead sleeve should then be slipped over the splice while still hot, and the surface of the lead of the sheath and of the sleeve having been thoroughly cleaned, the sleeve should be secured to the sheath at each end by a plumber's wiped joint. In the making of this joint, the services of a good plumber will be required, and the work should not be left until the joint is perfectly made, thus furnishing as good a protection to the conductors within as the sheath of the cable itself.

155. The finished joint is shown in Fig. 66. After making a splice, the conductors should be tested out for crosses

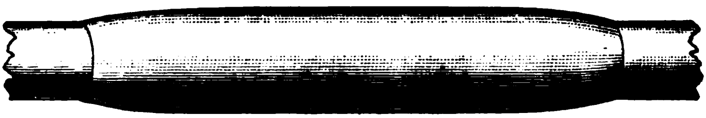


FIG. 66.

and continuity. The end of a cable should never be opened during rainy or foggy weather, as enough moisture will enter the cable to cause considerable injury. If caught in a shower while making a splice, great care must be taken to protect the cable ends from moisture by thoroughly soaking them in hot paraffin and wrapping them with canvas. If the end must be left for a considerable time, the sheath should be sealed with lead by a plumber's wiped joint.

156. In England, the joints, before filling with compound and putting on the lead sleeve, are often dried by placing them in a trough of heated lime. The heated lime will absorb the moisture from the paper of the cable. When thoroughly dried in this way, each joint, which has already a paper sleeve over it, is wrapped closely with plain tape.

CABLE TERMINALS.

157. Where a cable ends either in a central office or upon a pole, means must be provided for connecting the wires in the cable to the wires leading from it; and especially in cable terminals located out of doors, it is necessary to provide means for excluding all moisture.

158. Box Terminals.—Various forms of cable terminals may be procured upon the market. These usually consist of a cast-iron box, capable of being hermetically sealed to the cable sheath, and having within a set of terminals to which the wires of the cable may be soldered. By means of conducting pins laid in insulating bushings through the sides of the box, the circuits are extended to the outside of the box, where connections are made with the outside circuits. One of these cable terminals is shown in Fig. 67. A brass sleeve *a*, secured to the bottom of the cast-iron box *B*, affords ready means for securing the cable sheath to the box in a water-tight and air-tight manner.

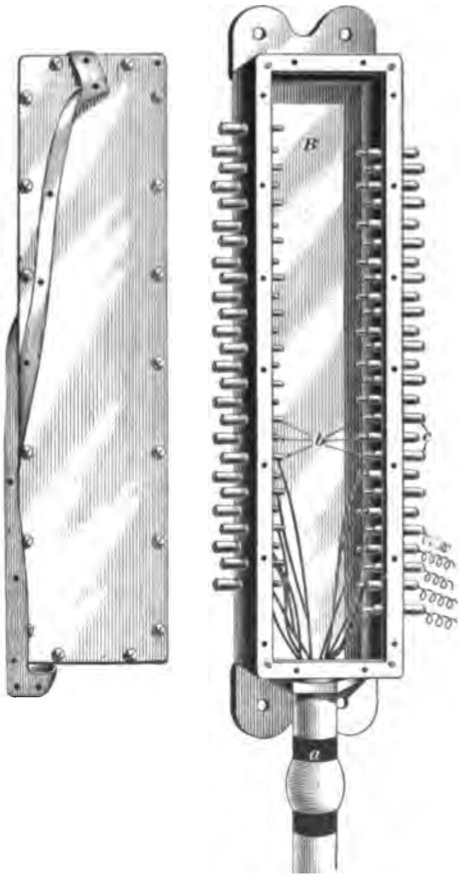


FIG. 67.

The various conductors from a cable are led up within the box and soldered to the individual terminals *b*, which pass through the insulating bushings *c* to the outside of the box. After all connections are made within the box, paraffin, heated to about 300°, should be poured into and out of it until all moisture is expelled, after which, and while the box and wires are still hot, the cover should be put on and secured in place, a rubber gasket serving to make the joint tight. Connection may then be made to the outside wires in the ordinary manner. It is a matter of the greatest importance that a non-corrosive flux should be used in soldering the connection on the inside of the box.

159. Frequently the outside connections on the terminal boxes are provided with fusible strong current-arresters, in order to prevent injuries to the cable by the passage through it of heavy currents, such as might be caused by crosses with power or lighting wires. These arresters may be procured in large varieties of forms, each of which is usually adapted for some particular style of terminal box.

160. Pot-Head Terminals.—Some telephone men prefer to terminate their cables in what are known as "potheads," and these, when properly made, form thoroughly reliable terminals and have the additional advantage of being extremely cheap. In order to terminate a cable in this manner, the cable end is secured in an upright position, with the ends of the wires projecting about 15 inches, in the case of a 100-pair cable, beyond the end of the sheath. A sleeve of pure lead, one-eighth of an inch thick and having an internal diameter slightly greater than the external diameter of the cable sheath, is then slipped down over the cable and out of the way.

Pieces of good rubber-covered wire, in twisted pairs, and long enough to reach wherever desired, are spliced to the pairs of wire in the cable. A good wire for this is No. 20 B. & S. gauge Okonite, in twisted pairs, colored red and black. It need not have an outside braid. The red rubber-covered wire should always be connected to the red wire of the cable, in order to prevent confusion. Each splice should be covered with a paper sleeve and all splices should be kept within a space of 13 inches from the end of the cable sheath. The wires as they leave the cable should then be bound with several layers of heavy cotton twine or wicking, in such manner as to prevent the insulating compound that will be subsequently poured in from entering the cable. All the rubber-covered wires should then be taped together with Okonite tape in such a manner that about half of the taping will be below the surface of the compound when poured in. The spliced wires should then be opened up as much as possible, so as to allow room for the insulating compound to fill the spaces between them.

The Western Electric Company make a so-called flame-proof wire, which the Bell Companies now use quite extensively for inside exchange work, from pot-heads to distributing frames, for cross-connecting and for connecting to the switchboard. It comes in twisted pairs, one wire being red and the other drab. The tinned conductor is first covered spirally with wool insulation, and over this is a braiding, probably a mixture of wool and cotton.

161. A thin brass tube about 20 inches long and about ¼ inch in diameter should then be bound with twine alongside of the wires, with its lower end about even with the end of the cable sheath. After this, the lead sleeve should be drawn up over the splices until it laps over the cable sheath only about 1½ or 2 inches. It should then be securely wiped to the sheath by a plumber's joint. The lead sleeve should then be warmed with a torch until it can barely be touched with comfort with the hand, and some sealing compound, previously heated to about 350° F., should then be poured slowly through a funnel into the top of the brass tube. This should continue until the insulating mixture is within ½ inch of the top. The funnel may then be removed and the compound allowed to settle and cool. The next day, and from day to day thereafter for about a week, the tube should be filled with hot compound to make up for the settlement. After it has ceased to settle, the top of the lead sleeve may be dressed into contact with the Okonite tape wrapping, thus giving a rather finished appearance to the work. It is well to place a cross-mark on the outside of the lead sheath at the point where the brass tube ends at the top, so that it may be readily found when needed.

The reason for using the brass tube, instead of pouring the insulating compound directly in the top of the lead sleeve, is that by so doing the mixture is forced to the bottom of the joint, from which it proceeds slowly upwards, thus expelling all the air. The insulating compound may be purchased from various cable manufacturers and wire dealers, and in ordering it care should always be taken to specify the purpose for which it is to be used. A good way to test whether or not the compound is too hot is to dip a piece of Okonite wire into it, holding it there for about two minutes; if upon withdrawal the insulation upon the wire is softened so as to readily peel off, the fluid is too hot. If, however, the insulation remains firm, the mixture is not too hot.

OVERHEAD CABLE LINES.

SUSPENSION OF CABLES.

162. Messenger Wire.—Overhead cables are supported from a steel wire or rope stretched between the

TABLE 17.

Diameter. Inches.	Weight per 100 Feet. Pounds.	Estimated Breaking Strength. Pounds.
$\frac{1}{2}$	51	8,320
$\frac{15}{32}$	48	7,500
$\frac{7}{16}$	37	6,000
$\frac{3}{8}$	30	4,700
$\frac{5}{16}$	21	3,300
$\frac{9}{32}$	18	2,600
$\frac{17}{64}$	15	2,250
$\frac{1}{4}$	$11\frac{1}{2}$	1,750
$\frac{7}{32}$	$8\frac{3}{4}$	1,300
$\frac{3}{16}$	$6\frac{1}{2}$	1,000
$\frac{5}{32}$	$4\frac{1}{2}$	700
$\frac{9}{64}$	$3\frac{1}{2}$	525
$\frac{1}{8}$	$2\frac{1}{4}$	375
$\frac{3}{32}$	2	320

poles. These are termed messenger wires, and usually consist of several strands of steel wire twisted together to form a cable. Table 17 gives the weight per hundred feet and the estimated breaking strength of the various sizes of messenger wire from $\frac{3}{32}$ inch in diameter to $\frac{1}{2}$ inch in diameter.

For the supporting of the heavier cables, containing 100 pairs or more, nothing less than a $\frac{1}{2}$-inch stranded rope should be used. For small cables, the $\frac{3}{8}$-inch or even $\frac{1}{4}$-inch messenger wires will prove sufficient, provided the length of the spans is not excessive. The messenger wire may be supported directly from the pole by means of wrought-iron brackets, of which one type is shown in Fig. 68; or where a number of cables are to be run on the same poles, cross-arms for the cables may be made by bolting a piece of 3-inch angle-iron directly to the pole. This may be of any length required, and should project on each side of the pole to a sufficient distance to give room for the desired number of cables. The messenger wire may be supported beneath the angle-iron cross-arm by means of hooks, or it may be passed directly through the cross-arm, slots being cut to the hole in such manner as to allow the messenger wire to be readily slipped in, and at the same time to prevent it from accidentally escaping. The messenger wire should be drawn up tightly by means of a block and tackle, and firmly anchored at its ends and at frequent intermediate points, so as to prevent any great length of it going down should a fracture occur at any point.

FIG. 68.

163. Cable Hangers.—The cable is supported from the messenger wire by means of cable hangers, usually secured to the cable at intervals of 18 or 24 inches. For small cables, the latter distance, or even 30 inches, will suffice, but for 100-pair cables, it is better to put the hangers as close together as 18 inches. Many forms of hangers are manufactured for this purpose, the one shown in Fig. 69 being largely used and giving very satisfactory results. It is composed of malleable iron, and is readily clamped upon the cable by a special tool designed for the purpose. This tool and the method of using it in clamping a hanger to a cable is shown in Fig. 70. The broad band of the hanger is slipped over the cable at the desired point, and the tongs are then applied, as shown, thus squeezing the band of the hanger around the cable until the gap is entirely closed.

FIG. 69.

It is well, although not strictly necessary, to provide a piece of thin sheet lead about 1½ inches wide and long enough to almost encircle the cable, and to clamp this on under the hanger. This serves as an additional protection to the cable sheath, which is especially desirable where the sheath is extra light.

FIG. 70.

164. Cable Stringing.—When the messenger wire is in place and pulled up to the proper tension, a leading-up wire of the same material as the messenger wire should be secured to the end of the messenger wire and to a stake or other suitable anchor in the ground, at a distance of 75 or 100 feet from the last pole in the stretch. The reel upon which the cable is wound should then be placed a few feet beyond the stake, as shown in Fig. 71, and in such manner that the cable will unwind from the top side of the reel rather than the bottom. One or two grooved rollers or sheaves, mounted on convenient stands, as shown, are placed between the end of the leading-up wire and the cable reel in such manner as to support the cable in passing from the reel.

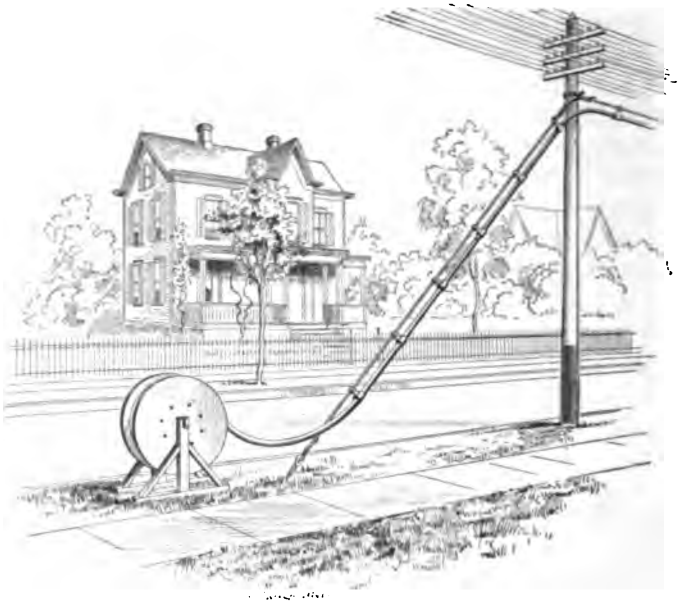


FIG. 71.

165. For drawing along the cable, a rope is first suspended directly under the cross-arms on the poles for the entire length of the stretch to be strung. A ½-inch hemp rope may be used, but a ¼-inch steel-stranded cable will prove more convenient. One end of this rope is attached to the end of the cable, while the other is secured to a capstan or windlass at the distant end of the stretch. As the cable passes over the rollers or sheaves, a man stationed at that point attaches the cable hangers, the cable being drawn slowly enough to allow him to properly do this. Another man hooks the hangers upon the leading-up wire as the cable begins its ascent. A man stationed on each pole lifts the hangers around the support or cross-arm as the cable proceeds.

166. It is not necessary to attach every hanger to the messenger wire while drawing up, and to save labor on the part of the men and facilitate the work, it is well to attach only every fifth or sixth hanger. This method may be followed until the forward end reaches the last span in the stretch, when a signal should be given for the man on each pole to hook every hanger upon the messenger wire as it passes. By this means the entire cable will be hooked up when it reaches its destination. The messenger wire should be permanently dead-ended before starting to pull up the cable.

167. An improvement on the method of drawing up cables is frequently followed where a large amount of cable is to be erected. This method is used extensively by the Standard Underground Cable Company, by whom it was developed. The hangers are attached to the cable in the usual way, but these are not hooked over the messenger wire during the process of drawing up. Instead of this, the cable rests in carriers, shown in Fig. 72, each consisting of a grooved wheel A, pivoted to a supporting stirrup C. The grooved wheel rests on the messenger wire, while the cable carrying the hangers is supported in the stirrup beneath. These carriers are applied at intervals of from 10 to 15 feet, and serve to support the cable while it is being drawn over the messenger wire. In order to make it unnecessary to remove the carriers from the messenger wire as they pass a cross-arm or support, switches or side tracks are clamped on the messenger wire at each cross-arm. These serve to engage the wheel of the carriers and guide them down under the cross-arm and again up on the other side and back on to the messenger wire. These switches are so made as to be readily bolted to the messenger wire. When the cable is all pulled up except the last section, men stationed at each pole place the hangers on the wires and remove the carriers as they pass, so that when the last section is pulled into position, all hangers are in place. The

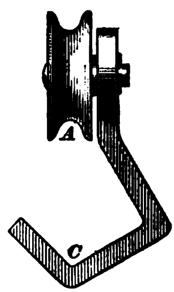


FIG. 72.

switches or side tracks are then removed, leaving the cable permanently suspended. Cable should be ordered from the factory in certain specified lengths, and these lengths should be so proportioned that the joints will come at the poles and not in the middle of the spans. It is always well to allow a few feet of slack in each section of cable, in order to allow room in the future for making necessary splices as repairs are needed.

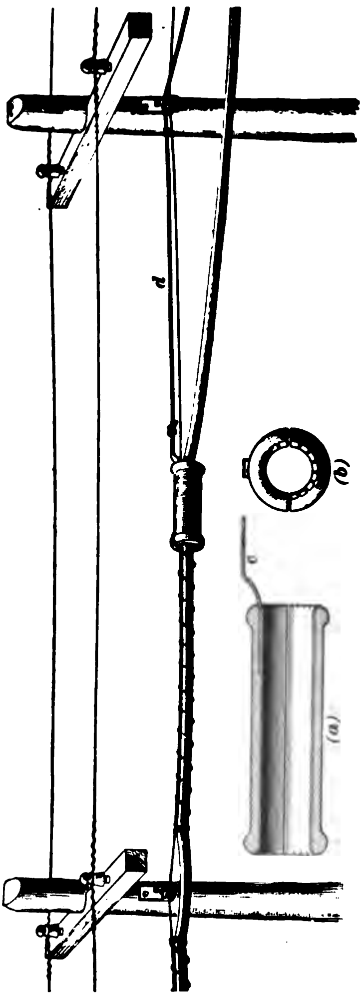


Fig. 73.

168. Aerial telephone cables are frequently supported by wrapping the cable and supporting wire with strong marline rope or twine, as shown in Fig. 73. The cable is drawn up to the supporting wire and wrapped to it with the marline by means of the Chinnock cable winder, commonly called the "spinning-jenny." The device, as shown in Fig. 73, consists of a bobbin made in two halves, with a hole through the center large enough to allow the cable and supporting wire to pass through it. (*a*) is a sectional and (*b*) an end view of the winder. The inside of the bobbin is nicely lined with copper, to make it smooth and wear well.

To use the device, place the two halves over the cable and supporting wire, fasten them together by the hooks or other means provided, and wrap on enough marline to support the cable between two poles. Fasten one end of the marline at one pole as shown in the figure, and by pulling the bobbin along by means of a rope d attached to the projecting hook c, the marline twists itself spirally around the cable and supporting wire, draws the cable up close to the wire, and the bobbin pushes before it the slack of the cable. When it reaches a support, the bobbin must be removed, replaced on the other side of the support, and again wound with marline. Sometimes two wrappings of marline are used in order to make the cable more secure, requiring the process above described to be repeated between supports.

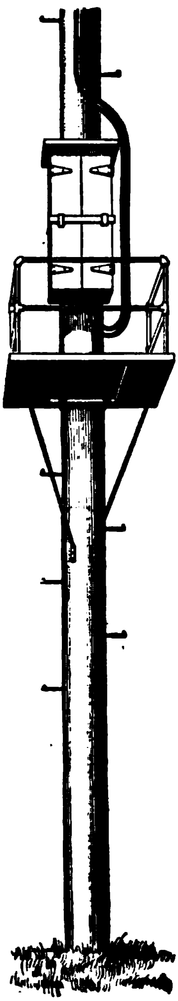


FIG. 74.

169. Pole Balconies. — Where an aerial cable line ends for the purpose of connecting with an underground line or with bare overhead wires, or where an underground cable terminates for the purpose of connecting with overhead lines of bare wire, suitable cable terminals, such as already described, should be provided on the pole and enclosed in a water-proof box. In order to facilitate the work of making connections, and the subsequent testing out of lines, a balcony should be built below the box containing the terminals. A pole thus equipped is shown in Fig. 74.

UNDERGROUND CABLE LINES.

CONDUITS.

170. Underground construction work is becoming of more and more importance, for the increasing number of uses to which electricity is put renders the number of circuits in city streets so numerous as to be a constant menace to both life and property when placed overhead. Besides this, their appearance is, to say the least, unsightly, which is in itself a sufficient reason for the city authorities to demand their being placed underground. Another strong argument in favor of placing wires underground is that they are not liable to injury from storms or fires, and that the cost of maintenance of the plant, when once properly installed, is less than if the wires were placed overhead.

171. It is almost universal practice in this country to place underground electrical circuits in conduits. In many places in Europe, the cables are laid directly in trenches, which are afterwards filled up, thus leaving the cable permanently buried. This practice is followed but little in this country, it having several disadvantages, chief among which are the difficulty of access to the cable for the purpose of repairing faults, the liability of the cable to injury from chemical action due to moisture and other elements in the soil, and the liability to mechanical injury from the pickaxes of workmen.

172. Open-Box Conduit.—The first conduit used in this country consisted of a wooden box or trough, made from 1½-inch rough lumber and large enough to contain all the cables needed. After digging the trench, the bottom is approximately leveled to grade, after which the trough, open at the top, is laid, the various sections being butt-ended and held in alinement by a short strip of board nailed along one side and lapping over the joint for a distance of about a foot on each side. After the conduit is laid, the reel containing the cable is mounted on wheels and drawn alongside the trench, the cable being unreeled and carefully laid in the bottom of the box as it proceeds. When all the cables have been laid, the box is filled with hot pitch, melted in any convenient manner, preferably in a wagon similar to that used for the same purpose in asphalting streets. The cover of the box is then nailed on and the trench refilled. The highest points in the conduit should be left open for some days, so as to provide means for pouring in additional pitch to make up for the room left by settling.

173. Cables laid in this manner have given very good satisfaction, and the method is, to say the least, an inexpensive one. It is, however, subject to one very serious difficulty, and that is due to the inability to make subsequent extensions. It is almost impossible to predict, at the beginning of the work, the number of circuits that will be required in a given line of cable; and, moreover, to install as great a number as may be needed in the future involves a greater expense than most companies desire to bear at the outset. Forms of conduit have therefore come into general use that allow of an almost indefinite extension of the cable system to meet the subsequent growth of the exchange.

174. The conduits may be of either wood, clay, or iron, and are usually provided with a number of ducts extending as nearly as possible in straight lines between manholes, in such manner as to allow the cable to be drawn in or out, as desired, with but very little trouble. Systems of this kind may be classified under the heading of "Flexible Conduit Systems," the term referring to the possibility of making changes in the arrangements and numbers of cables rather than to the possibility of actually bending the conduits themselves.

175. The Creosoted Wood Conduit.—A form of conduit largely employed, and one having the advantage of being very cheap to install, is one composed of sections of wooden tube, the fiber of the wood being impregnated with creosote in order to prevent its decay. This form of conduit is

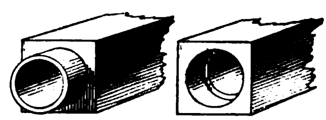


FIG. 75.

commonly known as pump-log conduit, on account of the resemblance of the wooden sections to the ordinary form of wooden pump logs. A section of this conduit is shown in Fig. 75, the ends being doweled in order to preserve the proper alinement in joining. These sections are usually 8 feet in length, and have circular holes through their centers from 1½ to 3 inches in diameter, according to the size of cable to be drawn in. The external cross-section is square and 4½ inches on the side, in the case of a tube having a 3-inch internal diameter. Such a conduit as this, if properly impregnated with creosote, will probably have a life of from 15 to 20 years, and perhaps much longer, this point being one concerning which there is considerable argument, and which probably time alone will decide.

176. In laying a pump-log conduit, a trench is usually dug several inches wider than the number of ducts to be laid side by side require, and after properly grading the bottom of the trench, a 2-inch creosoted plank is laid throughout its length for a foundation. The conduits are then laid in as many layers as are required, the ends being merely butted together without further precaution for securing perfect joints. In laying the tubes, however, the joints between the different layers should be broken as much as possible, in order to give greater strength to the structure. The sides of the trench are filled in and thoroughly tamped as the work progresses, and after the required number of ducts are in place, another 2-inch creosoted plank is placed above them, after which the trench is filled in and the pavement relaid. In digging the trench for this form of duct, it is well to make it of such a depth that the top plank will not be less than 2 feet from the surface of the street.

177. Cement Line-Pipe Conduit.—This conduit, made by the National Conduit and Cable Company, is now largely used for telephone and other underground wires. The sections shown in Fig. 76 are usually 8 feet long and are made as follows: A tube is made of thin wrought iron, No. 26 B. W. G., .018 inch thick, and securely held by rivets 2 inches apart. The tube is then lined with a wall of Rosendale cement ⅝ inch thick, the inner surface of which is polished while drying, so as to form a perfectly smooth tube. This comes in three sizes, each having a length of 8 feet and internal diameters of 2, $2\frac{1}{2}$, and 3 inches, the latter being the standard size. Each end is provided with a cast-iron beveled socket-joint, by the use of which perfect alinement may be obtained by merely butting the ends together. These beveled-socket joints also allow of slight bends being made in the line of conduit as it is being laid.

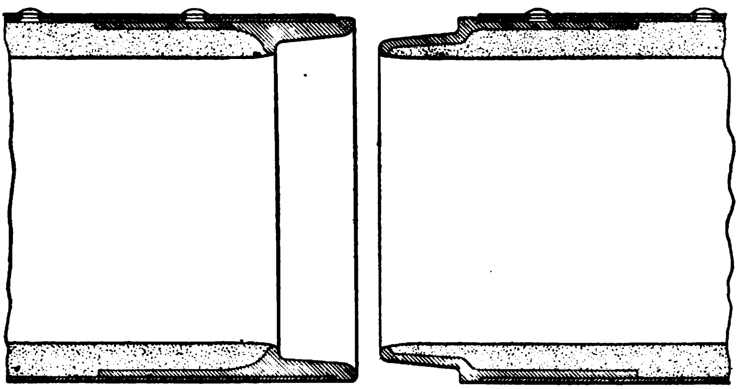


FIG. 76.

178. This conduit is laid in a trench, the bottom of which is first properly graded and then filled with a layer of from 4 to 6 inches of concrete composed of broken stone, sand, and cement. The tubes are then laid in layers until the required number is in place, being thoroughly embedded in good cement mortar, and the sides of the hole being filled in with concrete as the tubes are laid. On top of the entire structure is placed a layer of from 4 to 6 inches of concrete, after which the trench is entirely filled with earth. The trench should be of such depth that the top of the upper layer of concrete will be at least 2 feet below the surface of the ground.

In laying this conduit, special attention should be given to carefully covering the joints with cement mortar, as in this way the conduit may be rendered perfectly water-tight. It is usual to allow about 1 inch of space between the layers of ducts and to make each layer break joints with the preceding one, in order that the whole structure may possess considerable lateral strength. It is frequently advantageous to build in the sides of the trench a wall of rough boards, in order to prevent caving in of the sides and also to confine the cement mortar while setting. A view of a partially completed conduit line constructed with cement line pipes is shown in Fig. 77. This line consists of four layers of 8 ducts

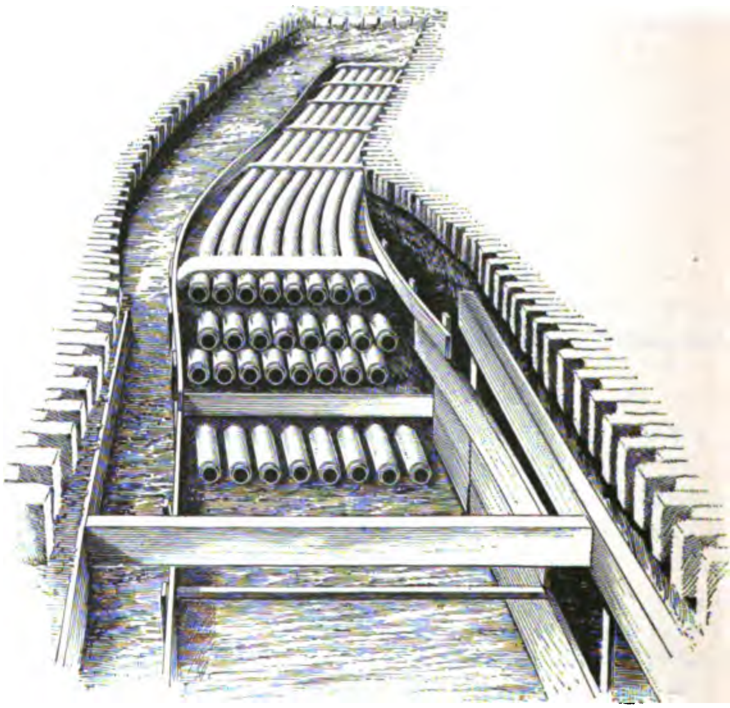


FIG. 77.

each, making 32 ducts in all. This shows also how curves may be made in the line when necessary. Such curves should always be made with caution, and it is much better, if possible, to continue the line of conduit in a straight line between the manholes.

179. Cement-Arch Conduit.—This is a conduit recently devised by Mr. C. H. Sewall, of Chicago, and seems to be meeting with much success in practice. This conduit is formed in arches made of cement molded over a network of wire cloth. The cross-section of one of these arches is shown in Fig. 78, the dimensions there given being those of the standard size of conduit. The wire cloth, which gives toughness to the structure, is woven from No. 20 B. W. gauge iron wire, with a mesh $\frac{3}{8}$ of an inch square. The cement is made of a mixture of equal parts of Portland cement and sand. The lengths of the section are usually 6 feet, although short sections may be procured, as well as curved sections, where it is necessary to make bends in the line of conduit. This conduit is laid on a previously prepared cement floor, the joints between

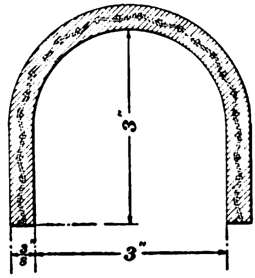


FIG. 78.

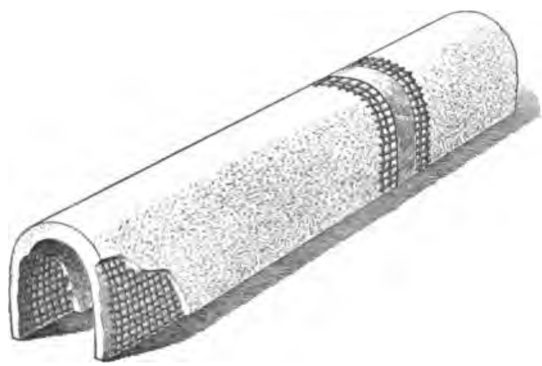


FIG. 79.

the sections being covered with an arch of wire gauze lined with cotton cloth, as shown in Fig. 79.

In laying this conduit, a trench is dug in the usual manner and the bottom filled with a layer of concrete about 4 inches in thickness. This concrete floor is troweled smooth and to an even grade from one manhole to the other. The arches are then dipped in water and laid upon this floor, a templet being used to secure the proper alinement. As soon as the first tier of arches is in position, it is immediately covered with concrete, which is then troweled smooth, forming a second floor, upon which the second tier is laid. This work

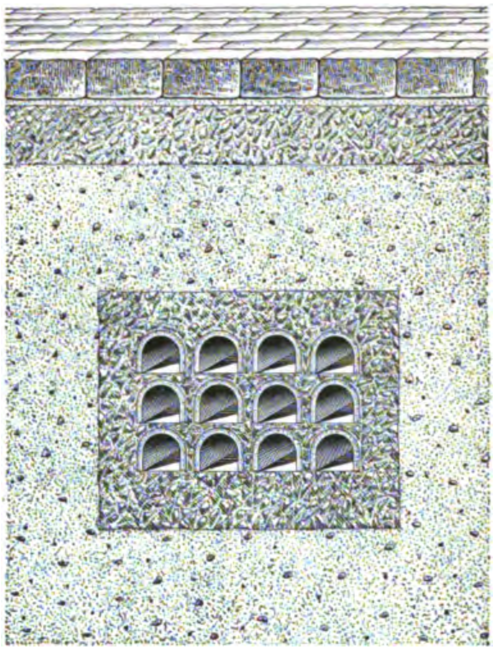


FIG. 80.

may be very rapidly done, as it is not necessary to wait for the complete setting of the concrete before the second and successive layers are laid. A cross-sectional view of a 12-duct line of this conduit is shown in Fig. 80.

180. Vitrified-Clay or Terra-Cotta Conduit.—A form of conduit that is probably used in good construction work to a greater extent than any other is made of vitrified clay. This material has the advantage of being absolutely proof against all chemical action, and unless destroyed by mechanical means will last for ages. Besides this, its insulating properties are high, and it is comparatively cheap and easily laid.

When clay conduits were first used, it was customary to form various sections with two or more ducts, one of the most common form being the 4-duct type, two sections of which are shown in cross-section in Fig. 81. These are made with 2, 3, 4, 6, and 9 ducts, all in 8-foot lengths. In another form, each section had two ducts only, these ducts being large enough to accommodate several cables. In this form, however, much trouble has been experienced, due to the fact that when several cables are laid in a single duct, it often becomes impossible to withdraw them, owing to the fact that they are much more likely to become wedged than in the forms where one cable only occupies a single duct. It is not good practice to put more than one cable in the same duct.

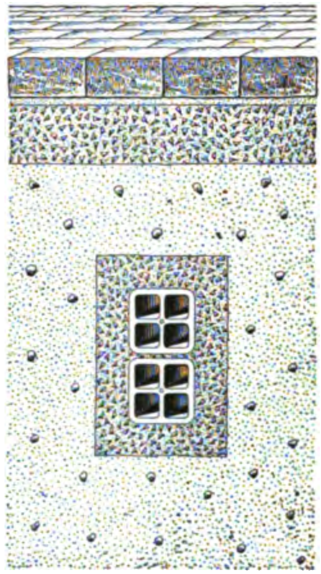


FIG. 81.

181. The form of clay conduits now most commonly used is shown in Fig. 82, this being usually made in lengths 18 inches long, having an internal diameter of from 3 to 3¼ inches, and being 4⅝ inches square outside. This duct has a great advantage over the multiple-duct sections, due to the greater ease of handling, and also to the fact that it is much less

FIG. 82.

liable to become warped or crooked in the process of burning during its manufacture than the larger and more complicated forms. Like the cement line pipe, it is laid on a bed of concrete, cemented together with mortar, and enclosed on all sides and on top by concrete. In

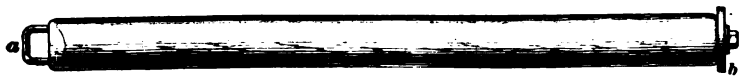


FIG. 83.

laying, a mandrel, such as is shown in Fig. 83, which is of wood, 3 inches in diameter and about 30 inches in length, is used. At one end is provided an eye *a*, which may be engaged by a hook in order to draw it through the conduit, while at the other end is secured a rubber

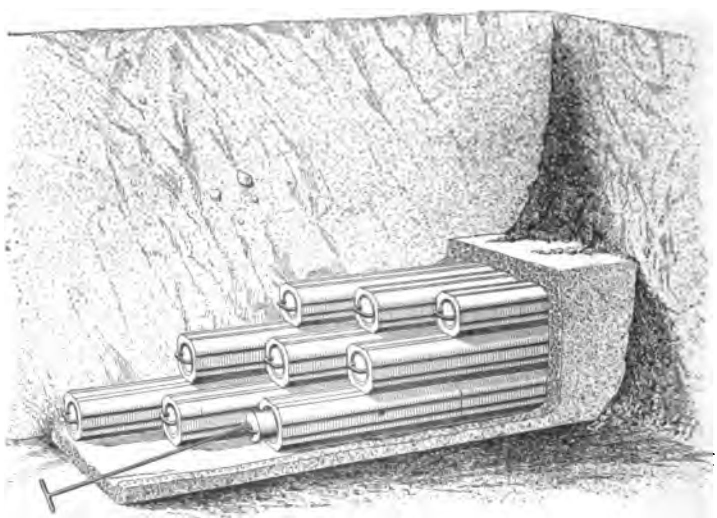


FIG. 84.

gasket *b*, having a diameter slightly larger than that of the interior of the duct. One of these mandrels is placed in each duct when the work of laying is begun. As the work progresses, the mandrel is drawn along through the duct by the workmen by means of an iron hook at the end of a rod about 3 feet long, the method of doing this being shown in

Fig. 84. By this means, the formation of shoulders on the inner walls of the ducts at the joints is prevented, and any dirt which may have dropped into the duct is also removed. The cylindrical part of the mandrel insures good alinement of the ducts, thus securing a perfect tube from manhole to manhole.

182. Fig. 84 illustrates well the method of laying this conduit, and shows clearly how the joints should be broken in the various layers so as to insure a maximum lateral strength to the structure.

All conduits should be laid to such grades that there will be no low points or traps in the conduit which will not drain into the manholes.

183. Concrete and Mortar for Conduit Work.—In nearly all modern types of conduit, except the creosoted wood, the use of concrete and mortar is required. Concrete forms the foundation for the structure, and is also used in filling in the sides and top of the trench, thus enclosing the entire structure of ducts in a continuous mass of this material. The concrete for this purpose should be made as follows:

Good cement......................	1 part;
Clean sand........................	2 parts;
Broken stone or screened gravel.....	5 parts.

The cement and sand should be first thoroughly mixed, after which a sufficient quantity of water should be added to form a soft mortar. The broken stone or gravel, in the proportion specified, should then be added, and the whole mass thoroughly mixed to a uniform consistency. Mortar is used for binding together the various sections of the ducts in much the same manner as in laying brick, and also to render the joints between the sections of a duct water-tight. A good mortar for conduit work may be mixed as follows:

Good cement......................	1 part;
Sand..............................	2 parts.

The cement and sand should be thoroughly mixed together while dry, after which water should be added to give the mixture the proper consistency for working.

MANHOLES.

184. Manholes form a very important part in cable systems, and require careful design to properly adapt them to the particular conditions to be met. They are usually placed about 400 feet apart, and if possible, at the intersection of streets. They should be located with a view to making the line of conduit between them as nearly straight as possible. The size of the manhole will depend on the number of ducts that are to be led to it, as well as the number of men that will be required to work in it at one time. Manholes 6 feet square and from 5 to 6 feet high will usually be required for large systems, while for smaller systems, or the outlying portions of large ones, they may be made as small as 4 feet in length in the direction of the conduit, 3 feet wide, and 3 or 4 feet high.

185. Manholes may be constructed of either cement or hard-burned brick laid in Portland-cement mortar, the latter probably being preferable. The foundation should consist of a layer of cement, the concrete at least 6 inches thick, mixed according to the proportion given in Art. **183.** The walls, if of brick, should be laid in cement mortar, mixed according to the formula for mortar given in Art. **183,** and should also be thoroughly plastered on the outside with the same mortar. They should never be less than 8 inches thick, and should frequently be made double this thickness where large manholes are being constructed in busy streets. As the brickwork is laid up, the iron brackets for supporting the cables around the sides should be built in. The roof should be of either arched brick or structural iron, supporting some form of cast-iron manhole cover, of which there are several types on the market.

It is rapidly coming to be considered better practice to thoroughly ventilate conduit systems than to attempt to make them gas and water tight. It seems almost impossible to prevent the accumulation in conduits of dangerous and explosive gases, and this being the case, it is necessary to provide means for both drainage and ventilation.

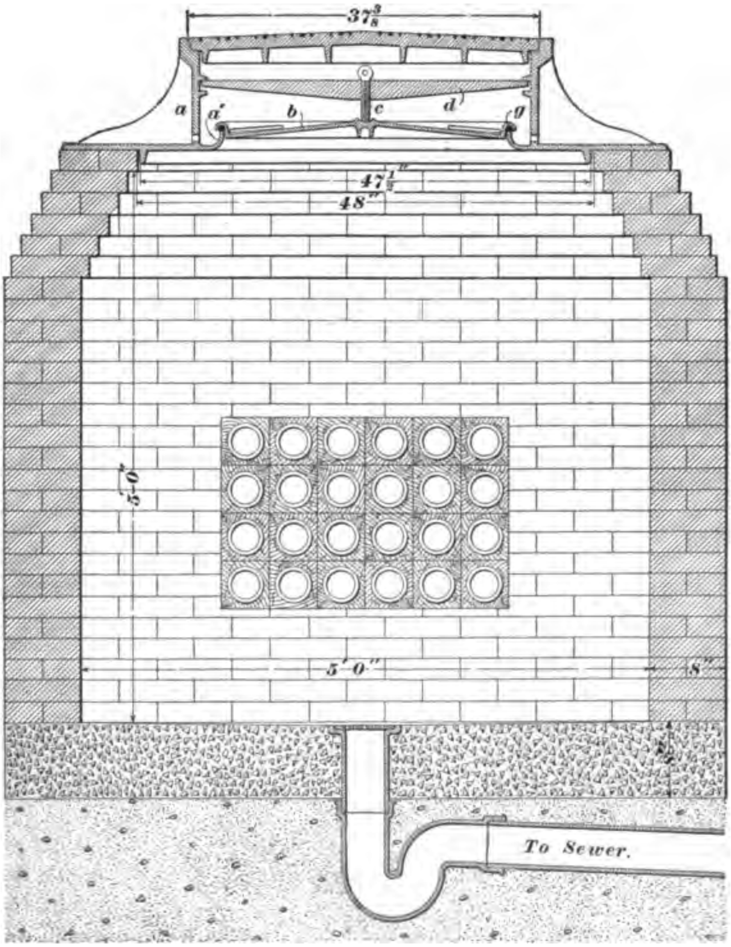


FIG. 85.

If the subway system is subject to illuminating and sewer gases, it is advisable to seal all the ducts where they enter the manholes with pure clay, plaster of Paris, or other suitable material that will not attack the cables, thus preventing the free circulation of gas from one manhole to another. Where the gases, as is sometimes the case, are so plentiful in the manhole as to render it unsafe for a workman to enter it, the gas is driven out by an ordinary hand blower.

186. In Fig. 85 is shown a manhole built of brick, with a cast-iron cover, designed to exclude all moisture. The dimensions of the manhole are clearly shown, the brickwork being corbeled in at the top, to support the manhole cover and frame. In this, the particular form of cover shown consists of a heavy frame *a* of cast iron, having an inner and an outer cover. The inner cover *b* rests upon an upturned flange *a'* of the frame, the connection between the two being made water-tight by a rubber gasket *g*. This cover is forced down upon the gasket by means of the screw *c* passing through a heavy rod or crosspiece *d* secured between flanges in the framework *a*. The outer cover is of cast iron, and made heavy enough to retain its place by gravity alone. The bottom of the manhole should be connected by a 6-inch clay tile pipe with the nearest sewer, this drain-pipe being provided with a ¾ S iron trap to prevent the entrance of sewer gas into the manhole. The conduits should be given an even slope, either from one manhole to another or from a central point in each direction to the manholes at each end of that section.

187. It is usually not necessary to provide water-tight covers for manholes when a connection is provided from the bottom of the manhole to the sewer. The connection with the sewer should remove all water from the manholes, while the use of a perforated cover greatly aids in ventilation. In many forms of manhole covers, a deep pan is suspended beneath the cover, which serves to catch all moisture and dirt falling through the holes in the cover without interfering with the ventilation. Where no drain-pipe is provided for the manhole, however, the water-tight cover is an absolute necessity. Conduit systems should either be as near gas and water tight as possible or else well drained and ventilated. In systems not gas-tight and not sufficiently ventilated, gases collect in the conduits and manholes and frequently explode, often doing considerable damage, and even resulting in loss of life.

INTRODUCING CABLES INTO CONDUITS.

188. Preparing the Duct.—Assuming that the line of conduit, or subway, as it is frequently called, and also the manholes are built, the first step before introducing the cables is to make sure that the ducts are all clear. This is usually provided for in the laying of the conduit, especially if the mandrel, shown in Fig. 83, has been used. The particles of dirt, however, may be readily removed by washing out the duct with a hose carrying a heavy pressure of water. In cases where this is not done, it is well to draw through the duct a mandrel carrying a gasket of leather or rubber, which will in its progress push all foreign matter before it.

189. Rodding.—The process of rodding is necessary in order to introduce a wire or rope into the duct for the purpose of drawing in the cable. This process consists of pushing a number of jointed rods into a duct from one manhole until the first rod reaches the other manhole. The rods are joined together by screw connections or by bayonet joints, as they are pushed in. When the chain of rods reaches between the two manholes, a rope or wire is attached to one end and pulled through, the rods being disjointed one by one as they reach the second manhole.

The introduction of a wire into the duct may often be greatly facilitated by using, instead of the rods, a steel wire about $\frac{1}{4}$ inch in diameter and provided with a ball about 1 inch in diameter at its end. This rod may be pushed through a smooth duct without trouble for distances up to

500 feet. If an obstruction is found during the rodding that can not be removed by means of the rods or by water, the distance to the obstruction can be readily measured upon the withdrawal of the rod. This distance can then be measured off along the ground over the subway, thus locating the spot where the obstruction occurs. The conduit should then be opened, the difficulty removed, and the structure repaired. This difficulty, however, should never be met where proper care is taken in the laying of the conduit.

190. Drawing In.—The process of drawing in is illustrated in Fig. 86. The cable reel should be mounted on

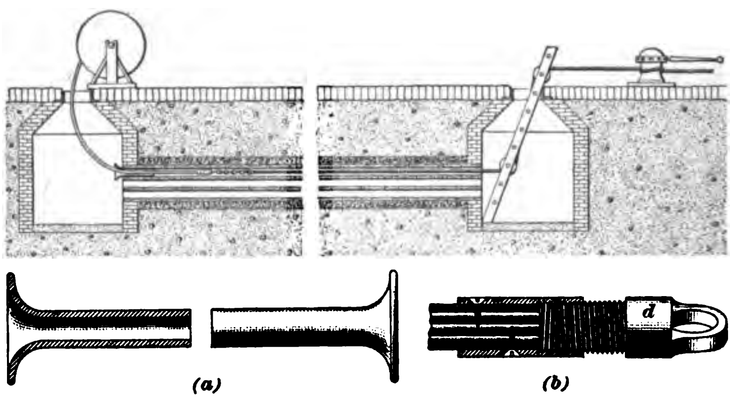


FIG. 86.

horses, so as to be free to revolve in such manner that the cable will unwind from its top. The end of the heavy rope leading through the duct should then be attached to the cable either by grips made especially for the purpose or by binding it with iron wire for a distance of 18 inches or 2 feet from the end. Fig. 86 (*b*) represents a section of a cable grip of iron pipe made to fit the cable snugly. It is fastened to the cable, as shown, by wood-screws, and the piece *d* to which the drawing-in rope is fastened, is screwed into the end of the iron pipe.

The drawing-in rope may be secured to the cable as follows: Punch two holes by means of a spike through the center of the cable from side to side, the first about 3 inches from the end and the second about 3 inches from the first; then form a link to connect the cable and the drawing-in rope by passing a No. 10 or 12 steel wire several times through the eye of the rope and the holes in the cable; fasten the ends of the wire so that they will not slip. This is a simple and cheap method, and the means for making it are easily procured.

Whenever a hole is made in the end of the cable for fastening the drawing-in rope, the end should be cut off when the cable has been drawn in, to remove all moisture, and then sealed if a joint is not to be made at once. The other end of the rope is passed over the grooved rollers, arranged on heavy planks mounted in the distant manhole, as shown, and should then be secured to a capstan or some form of windlass, by which a slow and steady pull may be exerted upon it. A man should be stationed in the manhole at which the cable enters, in order to properly guide the cable into the duct to insure against its being kinked or unduly strained. It is well to use a special funnel-shaped guide, made of wood or lead, at the entrance of the duct, in order to further insure the cable against injury by the corners of the duct. This guide is shown in Fig. 86 (*a*). It is sawed longitudinally into two sections, as shown in the left part of Fig. 86 (*a*), where the cable is to continue on through a manhole, and where it would, therefore, be impossible to remove the cylindrical protector if it were not sawed in two parts.

191. Arrangement of Cables in Manholes.—After the cables are drawn in, they are spliced, proper care being taken, of course, to connect no good wires to bad ones. Sufficient slack should be left within the manhole to allow the cable to pass along the sides instead of directly across them, so as to allow plenty of room for the workmen, and also to allow a certain amount of slack in case it is needed in making future repairs. It is a good plan to place a piece of sheet lead or of heavy felt or leather under each cable at the point where it emerges from the duct. This greatly reduces the liability to injury of the sheath at that point, due to the weight of the cable in the manhole. If the manhole is large, it is desirable that suitable support shall be arranged on its sides for the systematic support and arrangement of the cables. Sometimes racks are provided upon which cast-iron hooks are placed, this arrangement giving excellent satisfaction.

192. Distribution from Manholes. — It is usually the practice to run the cables that are to serve a certain district to a manhole located as near as possible to the center of that district, and to distribute from that point by means of overhead construction, although sometimes underground distribution to the points the wires are to serve is required. In this latter case, the service wires are usually led from the manholes in the form of small lead-covered cables enclosing one or more pairs, the service cables being led through iron pipes, if possible, to the basement of the building where the connection is to be made.

In passing from an underground to an overhead system, a cable pole is arranged in close proximity to the manhole. A 3-inch iron pipe is then led from the manhole and by a gradual bend upwards along the side of the pole to a point high enough to insure the protection of the cable from injury by passers-by. The cable terminates in a terminal placed in a box, as already described in connection with Fig. 74, and connection is made with the overhead circuits.

193. A construction similar to this is shown in Fig. 87, where means are provided for leading a cable from a handhole or distributing box to the cable pole. Handholes, such as is shown in this figure, are often used where a distribution center occurs between two manholes, and where it is not necessary to provide for access to all the cables. In this case, only those ducts that are to carry cables for this particular section are brought into the handhole, and for this purpose are laid on top of the subway, the through cables being carried in the ducts below, as shown. One or more 3-inch iron pipes *A* lead from the handhole to the pole, to which they are secured by means of wrought-iron straps. The construction of the handhole is shown quite clearly in this figure, this particular one being adapted for use with

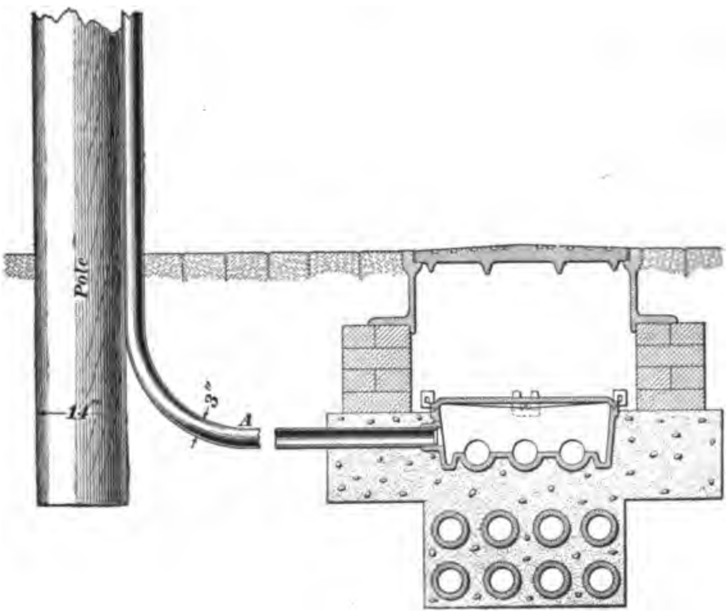


FIG. 87.

cement-lined conduit. It is a matter of great importance in this kind of work that the handhole should be free from moisture, for which purpose double water-tight covers are used. The ends of the pipe leading up the pole should be thoroughly sealed, in order to prevent moisture from trickling down the outside of the cable and entering the handhole in this manner. These pipes may be left open for ventilating purposes, in which case the service-box should be drained.

ELECTROLYSIS.

194. Earth-Currents.—Currents due to electric-railway or other systems carrying large currents and using earth returns are likely, in choosing their path back to the power station, to select the sheaths of underground cables, or of any other metallic bodies that offer paths of comparatively low resistance. This phenomena in general may be illustrated by Fig. 88. In this, the return current at the remote end of the trolley-line enters the earth, we will say, from the rails *R* and meeting with a line of water-pipe *W*, which forms a route to the power-house, selects this conductor as the return circuit. After a time this line of pipe may come in proximity to the line of telephone cables *C*, whose lead sheaths form a still better return path. The current will then follow this new-found conductor to some point where a more direct route is again found, and the current will emerge from the cable sheaths and enter the new conductor.

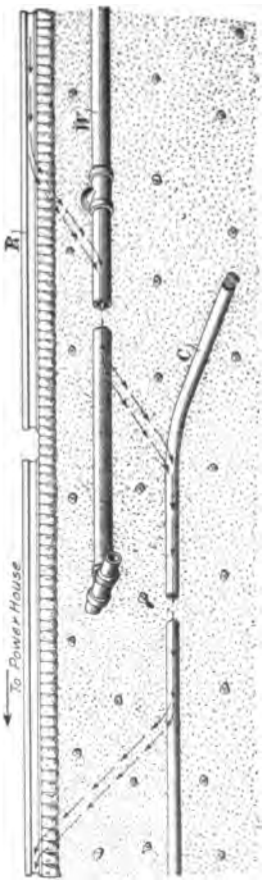


FIG. 88.

195. Danger Points.—Except in few cases, the current in flowing from one kind of a conductor to another will be compelled to pass through the earth, and it is at the points where the current emerges from the conductor and enters the earth that electrolytic action occurs, to the probable destruction of the conductor. Thus, in Fig. 88, the danger point on the cable sheath *C* would be that at which the current left the sheath in order to pass back to the earth and rails, no damage being likely to occur at the point where the current enters the sheath.

196. The use of conduits of highly insulating material, such as vitrified clay, goes a great way towards preventing the effects of electrolysis, but it is found necessary to use other means of protection for the cables. Especially is this true in all forms of conduit where no attempt is made to insulate the cable sheaths from the surrounding earth.

197. Locating Danger Points.—The method of procedure in each case in order to locate the danger points on

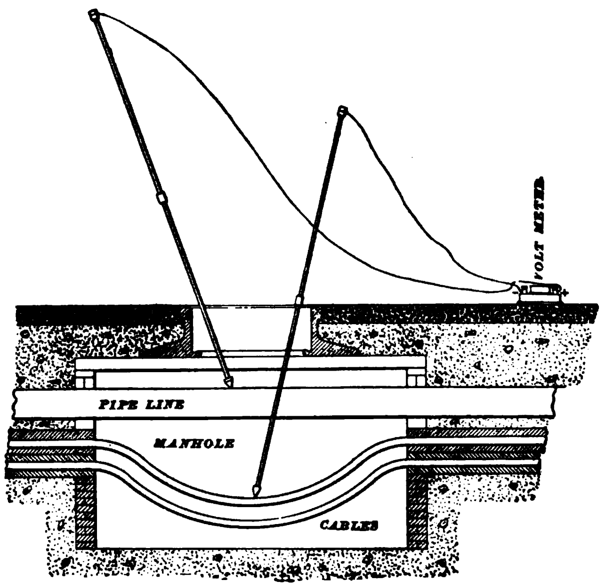


FIG. 89.

a cable is usually to measure the difference of potential between the cable sheath and the surrounding conductors, such as water-pipes or the rails of electric railways, at frequent intervals along the cable line. A convenient method of taking these measurements is shown in Fig. 89. Two brass rods of $\frac{3}{8}$-inch stock, about 10 feet long, should be provided. They should each be made in two parts, so as to be easily taken apart and put together again, and one should have a conical steel tip for making contact with the earth and other conductors, while the other should be provided with a wedge-shaped tip sufficiently sharpened to make a good contact with the cable and yet not so sharp as to injure it.

The construction of these rods is shown in Fig. 90. Upon opening the manhole, the rod should be connected with the

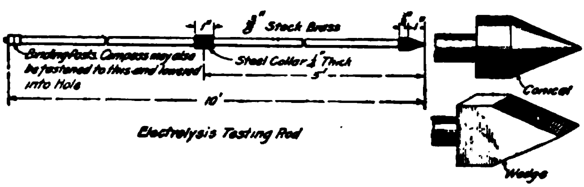


FIG. 90.

voltmeter by means of wires of suitable length, and the rod with the wedge-shaped tip should be touched to the cable, while the other one is successively touched to the earth, the duct, whatever pipes there may be in the hole, and to whatever other grounded conductors there may be in the vicinity.

Readings of the voltmeter should be taken at frequent intervals along the cable line and the results recorded in some such form as that shown in the following table:

Location of Manholes.	Reading from Cable.				
	To Earth. Volts.	To Water. Volts.	To Gas. Volts.	To Duct. Volts.	To Track. Volts.
1st Ave. and A St.	– 0.2	– 1.2	– 1.0	– 0.10	– 4.0
1st Ave., bet. A and B Sts.	– 0.3	– 1.2	– 1.0	– 0.10	– 4.2
1st Ave. and B St.	– 0.3	– 1.2	– 1.0	– 0.05	– 4.3
1st Ave. and C St.	– 0.3	– 0.9	+ 0.2	– 0.05	– 3.8
1st Ave. and D St.	– 0.4	– 1.0	+ 0.4	– 0.05	– 3.2
1st Ave., bet. D and E Sts.	– 0.4	– 1.0	+ 0.3	– 0.05	– 3.0

198. By means of such a table, made out for the entire length of the cable line, the danger points may be readily picked out. As long as the cable sheath is negative to all the surrounding conductors, it is in no danger from electrolysis, for this indicates that the current is flowing from the surrounding conductors to the sheath. If, however, a point is found where the cable sheath is positive to the surrounding conductors, we know that the current is then flowing from the cable to the other conductors through the ground at that point. The maximum positive point on the cable should be determined, and a heavy copper bond should be run from this point to the water-pipe or other conductor to which the readings indicate the current to be flowing.

The record given in the table would show that the maximum danger point in this case was at 1st Avenue and D Street, and a bond would therefore be required from the cable at that point to the gas-pipe.

199. Method of Bonding to Cable Sheaths.—With most telephone companies, a standard method has been adopted for bonding the cable sheaths. Bonds are placed between all the cables of an underground line in every manhole through which they pass. The wire used is No. 8 B. & S. gauge, bare copper, tinned. Fig. 91 will illustrate the method adopted for soldering the bonds to the lead sheaths. The surfaces of all the sheaths are scraped clean of mud, of which they are nearly always covered. In doing this work, an old file will be found useful, but great care must be taken not to cut away too much of the sheath. The end of the bond-wire *d* is then heated in a portable furnace and placed on the bright surface of the sheath and solder applied. A

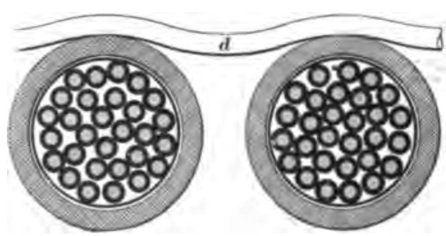


FIG. 91.

soldering-iron is then used to heat the sheath to the required temperature. The surface of the next sheath is then cleaned in turn, and the bond-wire bent down and soldered to it.

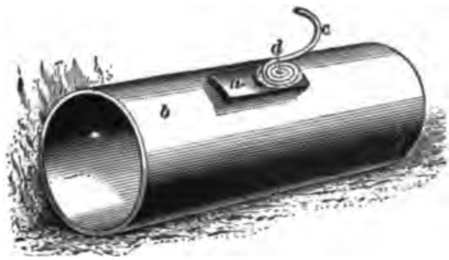


FIG. 92.

200. If the bond-wire is to lead to a gas-pipe, it may be soldered as in Fig. 92, in which *a* is a piece of sheet copper, which is soldered to the surface of the pipe *b*, which has been previously brightened and tinned. The bond-wire *c* is then coiled as at *d* and soldered to the copper plate.

201. It is impossible to solder to a water-pipe on account of the water rapidly conducting the heat away from the pipe itself. Where it is necessary to bond to a water-pipe, a yoke, shown in Fig. 93, may be made of strap

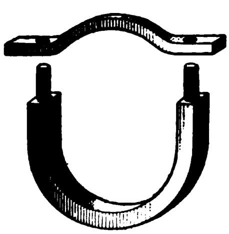


FIG. 93.

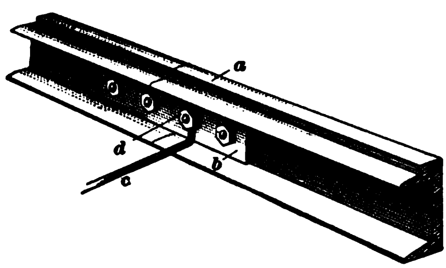


FIG. 94.

iron, and securely clamped in place upon the water-pipe, the surface of which has been previously brightened. The whole should then be given a heavy coating of asphaltum, to prevent corrosion.

The method of bonding to a rail is shown in Fig. 94, which needs no explanation, except to say that the contact surfaces must be clean and bright when the bond is made.

SUBAQUEOUS CABLE LINES.

CONSTRUCTION.

202. It is frequently necessary to extend telephone-lines under water, either in crossing rivers, bays, or lakes, or in extending lines from the main land to neighboring islands. For short lengths of cable across rivers or bays having smooth bottoms and slow currents, cables of the ordinary lead-covered type, preferably having rubber insulation, are frequently used, no special armor for the mechanical protection of the cable being necessary. It is well in such cases to order an extra heavy lead sheath, and also to cover the lead sheath with a heavy braiding of fibrous material saturated with water-proof compound.

In order to meet more severe conditions, special armored cables are required, these usually being in twisted pairs of the best rubber-covered wire, the whole bunch being embedded in rubber insulation or a heavy wrapping of jute,

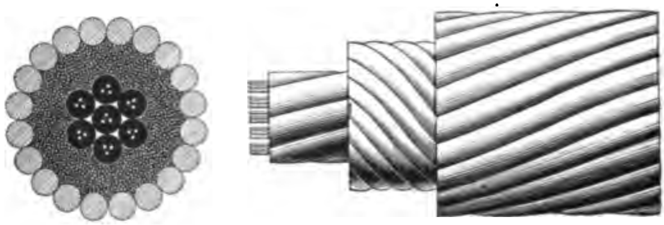


FIG. 95.

which is afterwards served with an armor composed of iron wire of about No. 10 B. & S. gauge, affording a continuous mechanical protection for the wires and insulation within. This construction is shown in Fig. 95.

203. For long under-water cables, where it is necessary to reduce the electrostatic capacity of the conductors to as great an extent as possible, a special paper insulation is sometimes used between the conductors. The Felten-

Guilleaume Company manufactures an excellent type of cable for this purpose. In Fig. 96 is shown a cross-section of a 4-wire cable constructed according to the same general principles as the aerial cable manufactured by the same concern, described in Art. **135.** The four conductors *a*, *a* and *b*, *b*, comprising two metallic circuits, are insulated from each other by a cross-shaped paper diaphragm *c*. The group is then wrapped by a spiral paper tube *d*, as previously described. This tube is then covered with a lead sheath *e*, after which a double coating *f* of gutta-percha insulation is applied. The iron armor consists of spiral wrappings of iron wire *w*, of the peculiar cross-section shown, this cross-section being adapted to cause an interlocking between the adjacent wires in such manner as to form an arch that will resist a large amount of compressive strain, besides giving the cable the requisite tensile strength. Over the iron armor is placed a heavy braiding of fibrous material saturated with water-proof compound. Cables built on this general plan are now being used successfully for telephonic transmission across the English Channel.

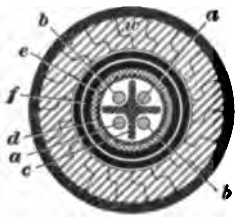


FIG. 96.

LAYING SUBAQUEOUS CABLES.

204. The means to be adopted for laying cables under water must be decided upon for each particular case. Of course, in laying comparatively long lines, the same methods that are followed out in the laying of submarine telegraph cables should be followed, the cable being coiled in tanks on a steamer and paid out over the stern by special apparatus as the vessel proceeds. In laying a cable across a comparatively narrow river, the reel on which the cable is wound should be mounted in the bow of the boat, so as to unreel over the stern of the boat, the cable passing from the under side of the reel. One end of the cable is secured to the shore at or near the point where it is to terminate permanently, after which the boat proceeds across the river, paying out the cable as it goes. Men should be stationed at the reel in order to regulate the tension of the cable as it unwinds, thus preventing too much slack. After reaching the opposite shore, the end is secured until permanent connections with the overhead or underground circuits can be made. The shore ends of the cable, extending as far out into the deep water as possible, should be buried in order to protect it from mechanical injury.

205. A method of propelling a boat across a river in a very nearly straight line, which may often be successfully used, is as follows: A rope is first stretched across the river between the points near where the cable is to terminate. This rope may engage running blocks on the bow and stern of the boat, thus serving to guide it across the river. The boat may be propelled by pulling it along the rope by hand, or, where the water is not too deep, by poling it.

206. Limitations of Submarine Telephony.—It has already been shown that telephone transmission through cables is very difficult on account of the high electrostatic capacity of the conductors. This difficulty is made greater in under-water work because the electrostatic capacity is rendered still higher by the presence of the armor and of the water outside of the cable, and also by the necessity of using insulating material having a high specific inductive capacity.

207. The problem of transoceanic telephony is at present, with our available knowledge of the subject, entirely beyond our reach. Many efforts are made to accomplish this by means of improvements in telephone transmitters and receivers, but, obviously, the problem must be attacked from a different standpoint. It is the transmission circuit and not the telephone instruments that are at fault. At present, submarine telephony is not practicable at distances much greater than 50 miles.

TESTING.

ROUGH TESTS.

208. The testing of circuits and apparatus is an important matter in all branches of electrical work, but in none more so than in telephony. The general methods described in *Electrical Measurements* are as a rule directly applicable to telephone work, but more specific directions than were given in that Paper may, now that an understanding of telephony is established, be given here. In testing either telephone lines or apparatus, it is frequently necessary to make rough tests to show whether or not circuits are continuous or broken, or whether they are crossed, grounded, or properly insulated. These tests do not require accurate measurement, they being merely for the purpose of determining the existence of a certain condition without the necessity for measuring accurately the extent to which that condition exists.

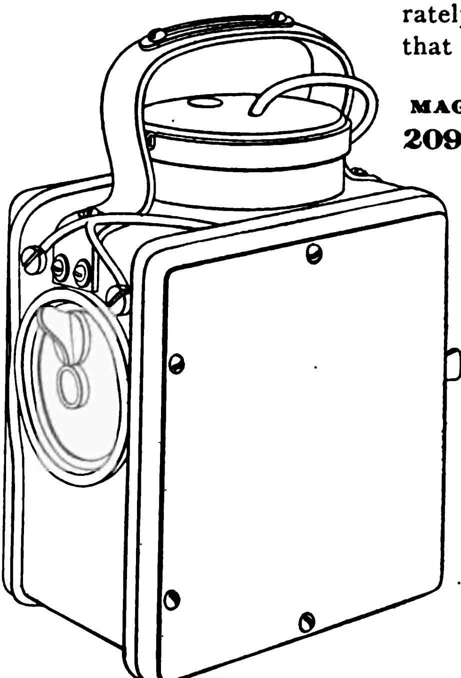


FIG. 97.

MAGNETO TESTING SET.

209. The most common, and probably, all things considered, the most useful, form of testing instrument is that consisting of a magneto-generator and polarized ringer, together with some simple form of telephone, all mounted compactly in a box provided with a strap for convenience in carrying. Such an outfit is shown in Fig. 97. The polarized bell is usually connected in series with the generator, which is preferably provided with an automatic shunt. The circuits of a good form of magneto testing set are shown in Fig. 98. In this, the polarized bell *R* is connected in series with the generator *G*, when the small switch *S* is in contact with the center button. When the switch is thrown to the left, the call-bell is cut out of circuit and the generator only is connected across the line terminals, this condition being advantageous when it is necessary to signal a distant station over a line that may be partially grounded or crossed. When the switch is thrown to the right, the magneto-telephone *T* is connected across the circuit, and may be used either as a transmitter or a receiver in communicating with another party on the line. When the generator is at rest and the switch thrown to the right, the telephone *T* alone is connected in the circuit between the binding-posts, the generator being shunted out of circuit by the automatic shunting device. If, however, the generator should be operated while the switch is in this position, the current from it will pass through the telephone and to line, thus producing a buzz in the telephone. By means of this, the party testing can often form some idea of the resistance or capacity of a circuit by the loudness of the buzz produced when ringing through the telephone.

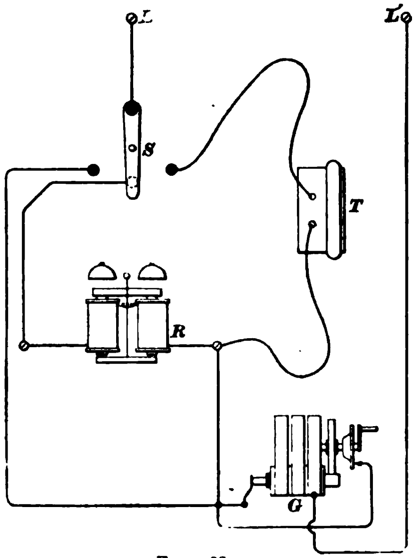


FIG. 98.

210. In many recent forms of testing sets, microphone transmitters and batteries for operating them are also included, but the addition of these parts is not to be recommended in general, as they greatly add to the weight of the instrument, and, besides, necessitate the use of switches that are not otherwise needed. One of the greatest points of merit to be considered in purchasing apparatus of this kind should be simplicity.

211. Continuity Tests.—In testing wires for continuity, the terminals of the magneto set should be connected to the terminals of the wire, and the generator operated, the switch of the testing set being thrown so as to include the ringer and generator in series. A ringing of the bell will usually indicate that the circuit is continuous. This is a sure test on short lines, but should be used with caution on long lines and in cables, because it may be that the capacity of the line-wires themselves will be sufficient to allow enough current to flow through the ringer to operate it even though the line or lines are open at some distant point.

212. Testing for Crosses.—In testing a line for crosses, either with the earth or with other conductors, one terminal of the magneto set should be connected to the line under test, both ends of which are insulated from the ground and from other conductors. The other terminal of the magneto set should be connected successively with the earth and with any other conductors between which and the wire under test a cross is suspected. A ringing of the bell will, under these conditions, indicate that a cross exists between the wire under test and the ground or the other wires, as the case may be, and the strength with which the bell rings and also the pull of the generator in turning will indicate in some measure the extent of this cross.

213. An experienced lineman can often tell with considerable accuracy the approximate location of a cross on a line by the sound produced by the bell or by the pull of the generator crank when the generator alone is thrown on the circuit. Here again, however, as in the case of continuity tests, the ringing of the bell is not a sure indication that a cross exists, if the line under test is a very long one. The insulation may be perfect and yet a sufficient current may pass to and from the line, through the bell, to cause it to sound, these currents of course being due to the static capacity of the line itself.

214. In testing very long lines or comparatively short lines of cable, the magneto set must be used with caution and intelligence, on account of the capacity effects referred to. For short circuits in local testing, however, the results may be relied upon as being accurate. Magneto testing sets are commonly wound in such manner that the generator will ring its own bell through a resistance of about 25,000 ohms. They may, however, be arranged to ring only through 10,000 ohms, or, where especially desired, through from 50,000 to 75,000 ohms. The first figure mentioned—25,000 ohms—is probably best adapted for all-around testing work.

CURRENT-DETECTOR GALVANOMETER.

215. In order to test for grounds, crosses, or open circuits on long lines or on cables, without the liability to error that is likely to arise in testing with a magneto set, a cheap form of galvanometer for detecting currents may be used. In testing for grounds or crosses, the galvanometer should be connected in series with several cells of battery, and one terminal of the circuit applied to the wire under test, it being carefully insulated at both ends from the earth and from other wires, while the other terminal of the galvanometer and batteries should be connected to the ground and to adjoining wires successively. A sudden deflection of the galvanometer needle will take place whenever the circuit is first closed, this being due to the rush of current into the wire necessary to charge it. If the insulation is good, then the needle of the galvanometer will soon return to zero, but if a leak exists from a line to ground or to the other wire with which it is being tested, the galvanometer needle will remain permanently deflected.

Tests for insulation can be made with considerable accuracy by this method if a battery consisting of about 50 cells is used, but if the resistance of an insulation is to be measured in megohms, the methods to be described under the heading of "Accurate Tests" should be followed.

216. In testing for continuity, the distant end of the line should be grounded or connected with another wire, known to be good, and the galvanometer and battery applied, either between the wire under test and ground or between the wire under test and the good wire. In this case, a permanent deflection of the galvanometer needle will denote that the wire is continuous, while if the needle returns to zero, it is an indication of a broken wire.

TESTS WITH TELEPHONE RECEIVER.

217. The importance of the telephone receiver as a testing instrument is greatly underrated. A good receiver is one of the most sensitive detectors of current known, and if connected in series with a battery, it may be used for rough tests in many cases with greater facility than the magneto testing set or the detector galvanometer.

218. Convenient Testing Set.—The ordinary watch-case receiver, with a head-band for attaching it to the ear of the user, together with one or two small-sized cells of dry battery, form a testing set that, for local work, is unsurpassed, and may be used in testing out cables for grounds or broken wires. If the set is to be portable, the batteries should be small enough to be carried in the coat-pocket of the user, and if two cells are used, may be bound together side by side by a wrapping of ordinary adhesive tape. One terminal of the battery is connected to one terminal of the head receiver, while to the remaining terminals may be connected flexible cords provided with terminals adapted to make contact with the various parts of the circuit that it is desired to test. This arrangement, while being capable of detecting the most feeble currents, has the further advantage of being light and of allowing the complete freedom of both the user's hands.

219. Method of Using Receiver.—In using the receiver for making rough tests for grounds or crosses in a cable, one terminal of the testing circuit, including the receiver and batteries, should be connected with the sheath of the cable, while the other terminal should be connected with the wire under test, which should be free from the other wires at each end. All the other wires in the cable should be bunched together at the near end of the cable and connected with the sheath. The wires at the distant end of the cable must all be carefully separated from each other and from the sheath, so that there is no possibility of a cross existing between them at that end. A click will be heard on closing the circuit with the wire under test, whether or not the wire is grounded, this being due to the fact that a small amount of current will flow into the wire even if it is properly insulated. If the wire is grounded, the flow of current will continue as long as the terminal is applied to the wire, but if the wire is well insulated, the flow will cease as soon as the wire has received its full charge. In order, therefore, to guard against misleading results, the terminal of the testing set should be tapped against the wire several times in succession; a continuance of the clicks will indicate that the wire is grounded, while the cessation of the clicks, after a few taps, will indicate that the insulation is good.

220. In testing for continuity with the receiver, all the wires should be bunched together at the distant end of the cable and connected with one terminal of the test battery by a separate wire leading to the end of the cable where the test is to be made. The other terminal of this battery should be connected to one terminal of the receiver, the other terminal of which may be applied to the separate wires at the near end of the cable, the wires at this end all being carefully separated from each other. A continuation of the clicks, upon tapping, will in this case indicate that the wire being tested is continuous, while the cessation, after a few taps, will indicate that it is broken. It is probably better, in making this test, to use an ordinary vibrating bell instead of a receiver, for then, if the wire is only partially ruptured so as to offer a very high resistance, it will not allow enough current to pass to ring the bell, while it would allow enough to pass to produce a decided click in the receiver.

IDENTIFYING WIRES IN CABLES.

221. It is frequently necessary when a certain wire has been picked out at one end of a cable, to identify that same wire at the other end in order that connection may be made with it. In order to do this, the wire desired should be grounded at one end, being carefully insulated from all the other wires. At the other end the wires should all be separated from each other and be free from the ground. A circuit containing a battery and a receiver or galvanometer detector or ordinary vibrating bell should then have one of its terminals grounded, while the other terminal should be applied successively to the various wires in the end of the cable. A continuation of the clicks in the receiver, a permanent deflection of the galvanometer detector, or a ringing of the vibrating bell will indicate when the wire desired has been touched.

222. Identifying Without Cutting.—It is frequently desirable to identify a wire at some intermediate portion of a cable without cutting the wire. This may be done by removing the sheath, or the outer coating, if the cable has no sheath, and loosening up the wires so that each one may be touched. The same test as that in the preceding article may then be made by using a needle-pointed terminal to the testing circuit that may readily pierce the insulation and make contact with the conductor within. This method will be found to save much trouble in the testing of switchboard cables, where it is often necessary to lead off branch wires from intermediate points of certain wires in the cable.

TESTING OUT CIRCUITS OF INSTRUMENTS.

223. When a case of trouble arises in a telephone instrument, a careful inspection of the instrument will usually reveal about what the nature of the fault is. For instance, if in the ordinary series instrument, having circuits shown in Fig. 87, *Telephony*, Part 1, it is found that the instrument will both receive and transmit *signals* to the distant station, but refuses to either receive or transmit *speech*, the inspector would at once conclude that the signaling apparatus and circuits were all right, and that the fault was somewhere in the talking apparatus or circuits. Furthermore, from the fact that the instrument would not receive speech, he would know that the fault was not in the primary circuit, because that circuit has nothing whatever to do with the receiving properties of the instrument. This would mean that something was wrong with the secondary circuit, and would probably indicate that this circuit was open at some point. A test to find out at what point this break occurs will be made as shown in Fig. 99, where the secondary circuit of the instrument shown in Fig. 87, Part 1, is illustrated.

224. In this figure, *A*, *A'* are the binding-posts of the instrument, *H* the hook switch, *1*, *2*, *3*, *4*, *5*, *6* the binding-posts at the bottom of the magneto-box, *S* the secondary of the induction-coil, and *R* the receiver. At the right of this figure is shown the testing set, consisting in this case of a magneto-bell and generator. A receiver and battery might be substituted for this, the test being performed in exactly the same manner. At *a*, *a'* are shown two convenient testing terminals, forming the ends of the testing circuit. The line-wires should be disconnected from the telephone at the binding-post *A* and *A'*. The terminal *a'* should be touched to one of the binding-posts *A'*, and for convenience it may be inserted in the binding-post in place of the line-wire. The terminal *a* should then be touched to the opposite binding-post *A*, when a failure of the polarized bell of the testing set to ring when the generator *G* is operated will show that the secondary circuit is open at some point. To locate this point is now an easy matter, and to do it we proceed as follows:

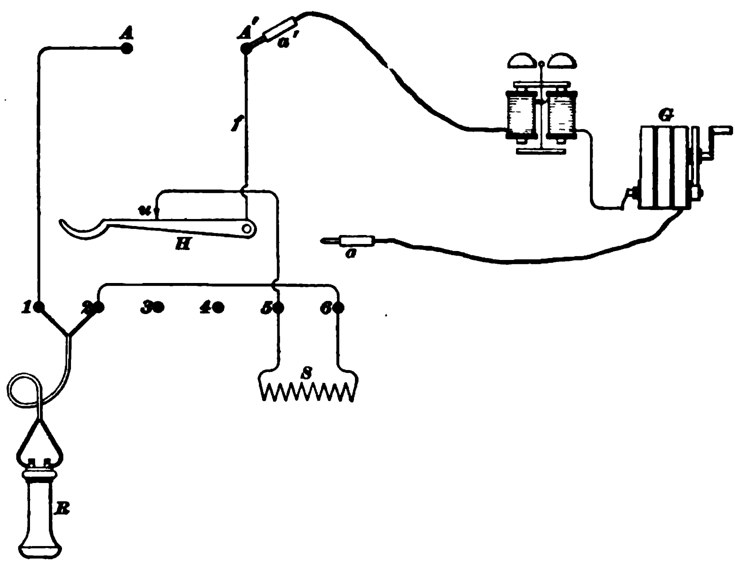


FIG. 99.

225. The terminal a' is left fastened in the binding-post A'. The magneto-generator is kept turning, preferably by another party, while the terminal a is applied successively to all the wires in the parts forming the secondary circuit of the telephone. It would first be applied to the wire f, a ring indicating that the circuit so far was unbroken. It should then be applied to the hook lever H, then to the upper contact u, and so on, point by point, the secondary circuit should be traced out with the point a. If, for instance, when the hook was up, the bell failed to ring while the terminal a was applied to the upper contact u, while it had responded when applied to the hook H, it would clearly indicate that the circuit was still open between the hook H and the upper contact u, and this contact should at once be carefully inspected and repaired. If, however, it was found that the circuit was completed as far as the binding-post *5*, while the bell failed to ring when the terminal was applied to the binding-post *6*, it would show that the secondary coil was open; and if an inspection of the exterior circuits leading to the coil failed to show the difficulty, the coil should be removed and another substituted. In this manner any circuit in a telephone may be readily tested out and the fault located to a nicety, after which the repair is usually a very simple matter.

ACCURATE TESTS.

MEASUREMENTS OF RESISTANCE.

226. The Wheatstone Bridge.—Measurements of resistance in telephone work is usually accomplished by means of the Wheatstone bridge, this instrument being very accurate for all resistances except those very large or very small, and possessing the additional desirable features of great simplicity and portability. The methods of using the Wheatstone bridge have been sufficiently treated in the Paper on *Electrical Measurements*, and need not be further dealt with here. It may be said, however, that the form of bridge best adapted for general telephone-testing purposes has a rheostat capable of being adjusted to any resistance from 1 ohm to about 11,000 ohms. The arms by which the ratio is obtained, corresponding to the arms *M* and *N* of Fig. 1002, *Electrical Measurements*, should be capable of having the values of 10, 100, and 1,000 ohms, thus being able to obtain multipliers from $\frac{1}{100}$ to 100.

227. The galvanometer for ordinary resistance measurements is preferably mounted in the same case as the resistance coils of the bridge, and with the keys for opening and closing the galvanometer and battery circuits. The galvanometer most suited for this work consists of a special form of D'Arsonval, in which the coil forming the needle is suspended in the field of a powerful permanent magnet.

These galvanometers have the advantage of not being affected by the proximity of other magnetic fields, and are, moreover, quite sensitive. Of course, for the most accurate tests, some form of reflecting galvanometer should be used. In some portable bridges, a battery is mounted in the same case with the other parts of the apparatus, this forming a very desirable feature and adding greatly to the ease with which rapid tests may be made, inasmuch as it is not necessary to carry extra batteries and to connect them up every time a test is to be made.

228. Measurement of Line Resistance.—In measuring the resistance of a line by means of the Wheatstone bridge, the terminals of the line circuit should be connected in the unknown arm of the bridge. Sometimes it occurs in the case of a grounded circuit that earth-currents will interfere to such an extent as to render accuracy impossible. In this case, if a parallel wire is available, the resistance of which is known, they may be connected together at the distant end and the resistance of the two in series measured. The resistance of the first will then be the difference between the total measured resistance and that of the known wire.

INSULATION TESTS.

229. In making insulation tests, the general methods outlined in Arts. **2520** to **2532**, inclusive, of the Paper on *Electrical Measurements*, may be followed in some cases. The general method used in telephony, together with the proper apparatus, will, however, here be described in some detail.

230. Galvanometer.—For tests of extreme accuracy, the Thompson galvanometer is best suited, but the use of this instrument is attended with many difficulties which render it unfit for many forms of practical work. As a laboratory instrument, however, where it can be properly shielded from the magnetic fields set up by neighboring electrical machinery or by trolley or lighting circuits, this instrument is unexcelled. The D'Arsonval galvanometer, however, is sensitive enough for nearly all practical work, and possesses the advantage of being entirely free from the effects of external fields. It is now made in portable form, so that it can be unpacked and set up in a few moments.

231. D'Arsonval Galvanometer.—The general form of D'Arsonval galvanometer used in this country is shown in Fig. 100, in which *P* are the permanent magnets by which the field of force in which the coil is suspended is maintained. The needle and suspension are mounted within the tube *T*, shown at the left-hand portion of this figure, this tube being removable from the frame of the instrument when it is desired to make any changes or repairs of the working parts within. The system, as the coil *N* and its supporting parts are termed, is shown in detail at the right of the figure. *R* is a rib supporting at the top and the bottom the torsion heads *B* and *F*. The rectangular coil *N* consists of many turns of fine wire, and secured to it above is a mirror *M* for reflecting a ray of light through the window *O* of the frame. The coil is suspended by a straight, elastic fiber *S* of some conducting material, such as phosphor-bronze, while the lower part of the coil is connected by a coiled spring *U*, usually of the same material, with the lower torsion head *F*. Current is led through the coil *N* by means of the suspension fiber *S* and the coiled spring *U*. The torsion of the suspension tends to hold the coil in a certain normal position, which position may be regulated by turning the torsion heads *B* and *F*, usually by turning *B* alone. When it is desired to move the instrument, the thumb-screw *A* at the top of the system may be tightened, thus drawing up the rod *L* and causing the fork carried by its lower end to engage a disk *Q*, which raises the coil just enough to remove its weight from the suspension fiber *S*.

This galvanometer is used in the same manner as the reflecting galvanometers described in the Paper on *Electrical*

Measurements. The lamp and scale may be used as shown in Fig. 988 of that Paper, but a better way is to mount a telescope carrying a horizontal scale directly in front of

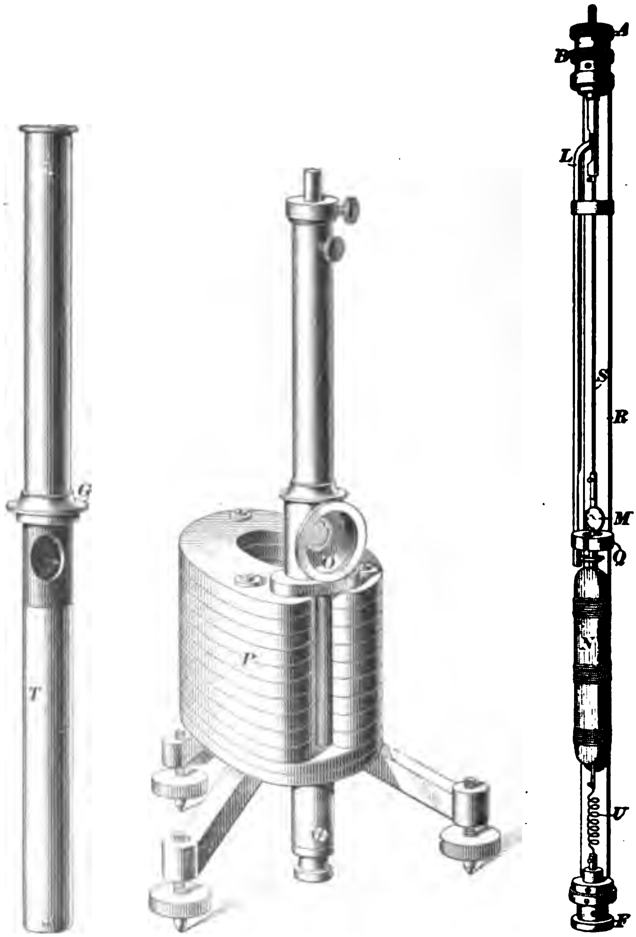


FIG. 100.

the galvanometer, in such manner that portions of the horizontal scale will be reflected by the mirror of the galvanometer into the tube of the telescope. Such a telescope and scale is shown in Fig. 101. Special scales are provided for this purpose, the numbers on which are reversed, so that when a reflection in the mirror is viewed through the telescope, they will appear normal. This method of reading the galvanometer is more desirable than that using the

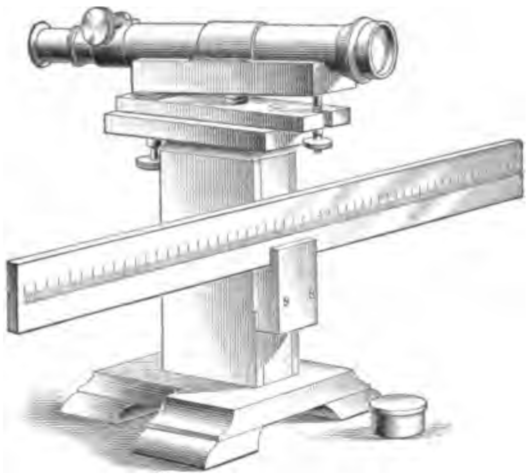


FIG. 101

lamp, because the readings may be made with greater accuracy by means of a cross-hair in the telescope, and, further, because the presence of a lighted lamp is not necessary. However, a lamp placed to illuminate the scale (not the galvanometer mirror) will often render the reading of the scale much easier.

232. Galvanometer Shunts.—The shunt accompanying the galvanometer should, of course, be adjusted to the particular resistance of the galvanometer coil, and should preferably have multiplying values of 10, 100, and 1,000.

233. Method of Measuring Insulation Resistance.—The method usually followed of measuring insulation resistance with a galvanometer is to first obtain the deflection through a known resistance, using a suitable known shunt around the galvanometer, with the given battery, and from it to calculate the deflection in scale divisions that would be produced were the entire current of the same battery to pass through the galvanometer and a resistance of 1 megohm. This latter quantity is called the working constant of the galvanometer. After the working constant is obtained, the deflection is taken with the insulation resistance of the line or cable substituted for the known resistance. In taking the galvanometer constant, it is usually necessary to use the shunt having a multiplying power of 1,000 (called the $\frac{1}{999}$-shunt), for otherwise the deflection would be too large to be readable.

234. Taking the Constant.—The circuits for taking the galvanometer constant are shown in Fig. 102, where G is the galvanometer, S the shunt, B a battery of 50 or 100 cells, and R a standard resistance, usually of 100,000 ohms, i. e., $\frac{1}{10}$ of a megohm. Upon closing the key K, a certain deflection d will be noted upon the galvanometer. If the shunt used has a multiplying power of 1,000, it is evident that without the shunt the deflection would have been 1,000 times as large, could it have been measured. Further, if a resistance of 1 megohm had been used instead of $\frac{1}{10}$ megohm, the deflection would have been only $\frac{1}{10}$ of d. Therefore, we may say that the deflection K produced by the current from the battery, passing through 1 megohm and through the galvanometer, without the shunt, would have been

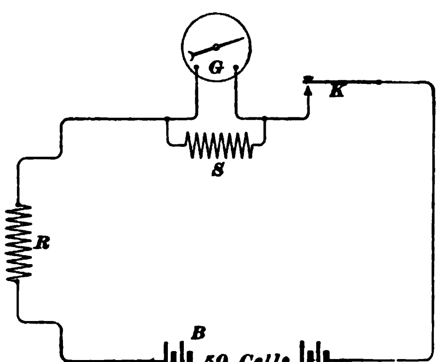


FIG. 102.

$$K = \frac{1,000 \times d}{10}.$$

If m represents the multiplying power of the shunt, d the deflection, and R the resistance *expressed in megohms*, then the constant K may be expressed by the formula

$$K = R \times m \times d. \qquad (10.)$$

The following general rule, therefore, may be given for calculating the constant:

Multiply the deflection by the multiplying power of the shunt and by the resistance in the standard resistance-box expressed in megohms or a fraction thereof.

In the case just cited, if the deflection d was 197 scale divisions, then the constant K would be equal to

$$197 \times 1,000 \times \tfrac{1}{10} = 19,700.$$

EXAMPLE.—In taking the constant, a $\frac{1}{10}$-megohm box was used and a deflection obtained of 247 scale divisions, the multiplying power of the shunt being 1,000. What was the constant?

SOLUTION.— $247 \times 1,000 \times \frac{1}{10} = 24,700$. Ans.

EXAMPLE.—In taking the galvanometer constant, a deflection of 143 scale divisions was obtained through a standard resistance of 2 megohms, the multiplying power of the shunt being 100. What was the constant?

SOLUTION.— $143 \times 100 \times 2 = 28,600$. Ans.

235. Deflection Through Insulation.—After taking the constant, the insulation resistance of the cable or line is substituted for the standard resistance, the connections being then substantially those shown in Fig. 103. All the wires of the cable, except the one being measured, should be bunched together and connected with the sheath, the sheath itself being grounded. At the start use, as a precaution, a small shunt, the $\frac{1}{999}$ or

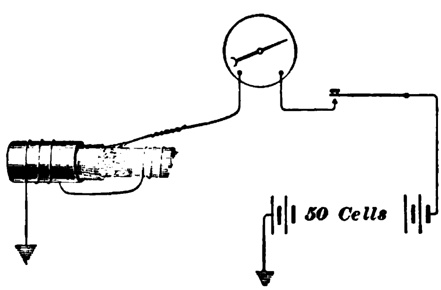


FIG. 103.

the $\frac{1}{10}$, whose multiplying powers are 1,000 and 100 respectively, and increase the resistance of this shunt until a suitable deflection is obtained. If the insulation resistance is rather high, usually no shunt (that is, a shunt of infinite resistance) will be required, and the shunt box can be cut out entirely, which is done by removing all the movable plugs. Upon the closure of the key, a certain deflection of the galvanometer will be obtained at once, but this deflection, instead of remaining constant as it did with the circuits as in Fig. 102, will be seen to slowly diminish, this being due to the electrification of the cable. The diminishing deflection would seem to indicate that the insulation resistance of the cable was increasing by the passage of the current; but this effect is due to electrification, which phenomena, as was pointed out in *Electrical Measurements*, is not thoroughly understood, but may be stated as being in the nature of a soaking in of the charge of electricity into the insulation. After about half a minute, on a short length of ordinary telephone cable, the electrification will practically have ceased; but the rule is, in taking insulation resistance, to allow one minute for electrification, after which the reading is taken.

236. Calculation of Insulation Resistance.—In making insulation tests at the factory, the whole cable, excepting the two ends, of course, is submerged in a tank of salt water. The manufacturers generally use as high as 200 volts in making this test. This requires a known resistance of 500,000 ohms (half a megohm) and the $\frac{1}{999}$ shunt of the galvanometer in order to obtain the constant K.

The constant K was obtained by calculating the deflection which the given electromotive force would have produced if the total resistance of the circuit was 1 megohm and no shunt had been used around the galvanometer. In taking the deflection through the insulation resistance, a certain deflection at the end of 1 minute was observed, which will be called d', the galvanometer shunt this time being one whose multiplying power will be called m'. Without this shunt it is evident that the deflection would have been

m' as large, i.e., $m' \times d'$, could it have been measured directly. It is also evident that the deflections, if no shunts are used, will vary inversely as the resistance in the circuit with the galvanometer, and therefore where X is the required insulation resistance, the following proportion will hold :

$$X : 1 :: K : d' \times m'.$$

Solving for X, we have

$$X = \frac{K}{d' \times m'}. \qquad \textbf{(11.)}$$

That is, *the insulation resistance is equal to the constant of the galvanometer divided by the product of the multiplying power of the second shunt used and the deflection obtained through the insulation.*

When the shunt resistance has an infinite value, that is, when it is cut out of the circuit and no shunt is used, the value of m' is 1. In such a case, X would be simply the constant K divided by the deflection d'.

237. This method is not strictly accurate, because the combined resistance of the galvanometer and shunt should be added to that of the known resistance and to that of the insulation resistance, in making the computations. However, the error introduced by neglecting this is usually so small that it is always neglected in making ordinary insulation tests in telephone work.

In order to determine the insulation resistance per mile, multiply the insulation resistance of the cable as measured by its length expressed in miles or a fraction thereof.

EXAMPLE.—In taking the constant of a galvanometer for an insulation test, a deflection of 184 scale divisions was obtained with a $\frac{1}{10}$-megohm box, and with a multiplying power of the shunt of 1,000. The deflections, taken through the insulation resistance of 5 wires, one at a time, in a cable 10,123 feet long, with a shunt whose multiplying power was 10, were as follows: 23, 19, 25, 32, and 21 scale divisions, respectively. What was the insulation resistance of each of the wires?

SOLUTION.—The constant of the galvanometer is equal to

$$184 \times 1,000 \times \tfrac{1}{10} = 18,400.$$

Insulation resistance, first wire, $\frac{18,400}{10 \times 23} = 80.0$ megohms. Ans.

Insulation resistance, second wire, $\frac{18,400}{10 \times 19} = 96.84$ megohms. Ans.

Insulation resistance, third wire, $\frac{18,400}{10 \times 25} = 73.6$ megohms. Ans.

Insulation resistance, fourth wire, $\frac{18,400}{10 \times 32} = 57.5$ megohms. Ans

Insulation resistance, fifth wire, $\frac{18,400}{10 \times 21} = 87.6$ megohms. Ans.

EXAMPLE.—What is the insulation resistance per mile of each of the wires in the preceding example?

SOLUTION.—Length of cable $= \frac{10,123}{5,280} = 1.917$ miles.

Insulation resistance per mile, first wire, $80.0 \times 1.917 = 153.36$ megohms. Ans.

Insulation resistance per mile, second wire, $96.84 \times 1.917 = 185.64$ megohms. Ans.

Insulation resistance per mile, third wire, $73.6 \times 1.917 = 141.09$ megohms. Ans.

Insulation resistance per mile, fourth wire, $57.5 \times 1.917 = 110.23$ megohms. Ans.

Insulation resistance per mile, fifth wire, $87.6 \times 1.917 = 167.93$ megohms. Ans.

MEASUREMENT OF LINE CAPACITY.

238. The simplest and probably the most satisfactory method for measuring the capacity of a line or cable is to compare the capacity to be measured with that of a standard condenser. It is first necessary to obtain the deflection of the galvanometer needle when the standard condenser is discharged through it. For this purpose the apparatus is arranged as shown in Fig. 104, in which G is the galvanometer, C the standard condenser, B a battery of from 1 to 15 cells, and K a discharge key resting normally against the contact b, but capable of being depressed against the contact a. The capacity of the condenser C should, if possible, be adjustable from about $\frac{1}{10}$ to 1 microfarad, but in case an adjustable condenser is not available, one having a capacity of about $\frac{1}{10}$ microfarad will be found most suitable for telephone work.

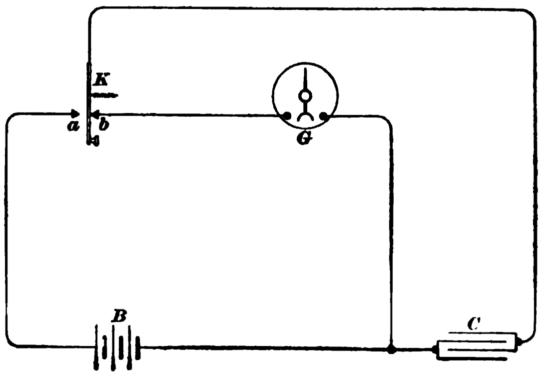


FIG. 104.

When the key is depressed, a current from the battery charges the condenser. The charging should be allowed to continue for about 15 seconds, in order to give the

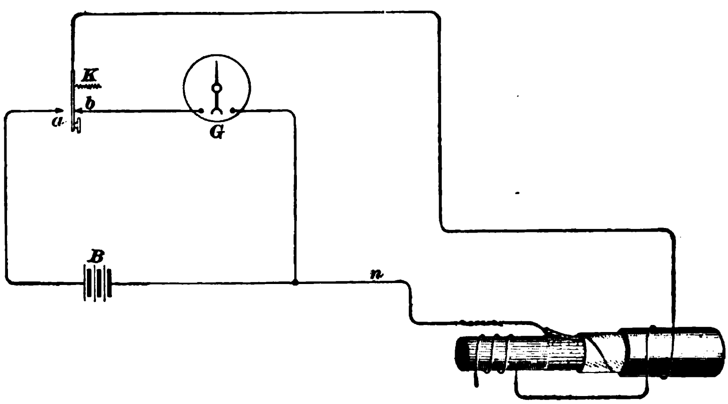


FIG. 105.

charge a chance to soak in. The key should then be suddenly released, which will establish such connections as to allow the condenser to discharge through the galvanometer.

A certain throw or kick of the galvanometer needle will take place, and this extreme reading should be noted down. Several readings should be taken to avoid error and to obtain an average. The cable or line is then substituted for the condenser, as shown in Fig. 105, where the wire *n* leading from the galvanometer and battery is connected to the wire of the cable to be measured, all the other wires being insulated from it and connected with the sheath of the cable. The key *K* should be connected to the sheath, as shown. If the line whose capacity is being measured is of bare wire, the wire *n* from the battery and galvanometer should be connected to it, while the wire from the key should be grounded. Several readings are then taken on the galvanometer, and the average of them obtained as before. Between readings, the condenser or line, as the case may be, should be fully discharged by holding the key in the discharging position for at least five seconds. If no shunt is used on the galvanometer, or if the same shunt is used in each case, the two capacities will vary in proportion to the respective readings of the galvanometer; thus, calling d the deflection obtained with the standard condenser, d' that with the cable, C the capacity in the standard condenser, and C' the capacity of the cable, we have

$$C' : C :: d' : d;$$

or,

$$C' = \frac{C \times d'}{d}. \qquad \textbf{(12.)}$$

If it is necessary to use a shunt in taking the readings from the cable or condenser, the corresponding deflections should be multiplied by the multiplying power of the shunt before using them in the formula. The use of a shunt in capacity tests should be avoided if possible.

The capacity per mile is found by dividing the total capacity by the length of the cable in miles. The best results are obtained when the capacity of the standard condenser is very nearly equal to that of the condenser, and the deflections therefore nearly the same.

EXAMPLE.—A test was made to determine the capacity of a cable. The capacity of the standard condenser was 1 microfarad. The deflection or throw from the standard condenser was 37 divisions, and that from the cable was 42. What was the capacity of the cable?

SOLUTION.— $C' = \frac{42 \times 1}{37} = 1.135$ microfarads. Ans.

THE LOCATION OF FAULTS.

239. Faults on a line may be of two kinds: The line may be entirely broken or it may be unbroken, but in contact with some other conductor, or with the ground. The former fault is termed a break; the latter, a cross or ground.

240. A break may be of such a nature as to leave the ends of the conductor entirely insulated, or the wire may fall or have its insulation impaired, so as to form a cross or ground. A cross may be of such low resistance as to form a short circuit, or it may possess high resistance, thus forming what is termed a leak. The location of faults is a matter often involving much ingenuity and mathematical knowledge. For locating the ordinary faults, such as usually occur on telephone lines or cables, the following methods may be relied upon.

TESTS FOR LOCATING A BREAK.

241. The location of a break in a wire can be determined by capacity tests, as the capacity of the part of a wire bears the same relation to the capacity of the whole wire as the length of the part does to that of the whole.

When one good wire, having the same capacity per mile, is accessible, a condenser need not be used, but instead deflections may be taken on the broken wire and on the good wire. Let D be the throw on the broken wire and D' the throw on the good wire. L is the distance to the break and L' the total length of the good wire. Then,

$$D : D' :: L : L';$$

or,

$$L = \frac{D \times L'}{D'}. \qquad \textbf{(13.)}$$

EXAMPLE.—A test was made to find a break in a cable conductor near to which ran another sound wire. The throw on the broken conductor was 35 divisions and that on the good wire was 80 divisions. What was the distance to the break, the total length of the cable being 3,100 feet?

SOLUTION.—Using formula **13**,

$$L = \frac{35}{80} \times 3{,}100 = 1{,}356 \text{ ft. Ans.}$$

EXAMPLE.—A break occurs in a cable 3 miles long. It is known that the capacity of the entire conductor was .39 microfarad per mile, or 1.17 microfarads in all. Upon testing, it is found that with a standard condenser of $\frac{1}{3}$ microfarad and a suitable battery and shunt to the galvanometer, the deflection is 98, while with the same shunt and battery, the deflection obtained from one end of the cable is 141. How far from the testing end is the break?

SOLUTION.—Using formula **12**, $C = \frac{1}{3}$, $d = 98$, $d' = 141$.

$$C' = \frac{\frac{1}{3} \times 141}{98} = .4796 \text{ microfarad.}$$

$$\text{Distance from testing end} = \frac{.4796}{.39} = 1.23 \text{ miles. Ans.}$$

EXAMPLES FOR PRACTICE.

1. In a test for the capacity of a cable, the capacity of the standard condenser was 2 microfarads. The throw produced by the condenser was 53 divisions and that by the cable was 32 divisions. What was the capacity of the cable? Ans. 1.207 microfarads.

2. A test was made to locate a break in a cable conductor. A sound wire was accessible. The throw on the broken wire was 29 divisions and that on the good wire was 75 divisions. The length of the tested cable was 5,760 feet. What was the distance to the break?
Ans. 2,227 ft.

TESTS FOR LOCATING GROUNDS OR CROSSES.

242. These faults occur much more frequently than breaks, and are often difficult to locate, especially if more than one ground or cross occurs on the same line.

Tests Without Available Good Wire.—The existence of a wire whose insulation and continuity are known to be perfect (such wires are usually termed good wires) is often a great aid in helping to locate a cross. Where no good wire is available, however, the following method may be pursued: Carefully insulate both ends of the wire from the ground and from other conductors. A Wheatstone bridge with a sensitive galvanometer is then connected between one end of the wire and the ground, as shown in Fig. 106, and the resistance of that end of the line-wire,

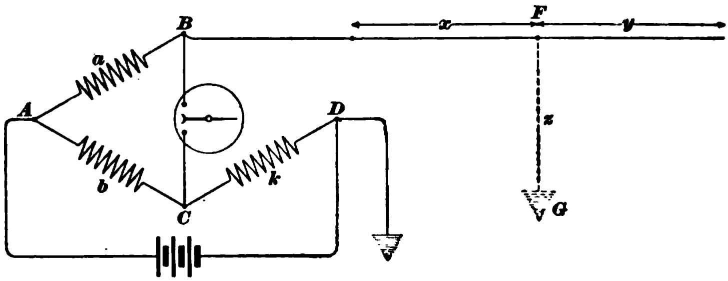


FIG. 106.

through the fault, to the ground, is measured. Let this resistance be r. The same test is now repeated at the other end of the line, and a resistance r' is observed. Call z the resistance of the fault itself, x the resistance of the line-wire from the first end to the fault, and y the resistance of the remaining portion of the line-wire. The first resistance measured, r, is the combined resistance of the first portion of the line-wire and the resistance of the fault. Thus,

$$r = x + z.$$

Similarly, $$r' = y + z.$$

Calling L the resistance of the line, we have the equation

$$L = x + y.$$

Solving these three equations for x, y, and z, we obtain

$$x = \frac{r - r' + L}{2}. \qquad \textbf{(14.)}$$

$$y = \frac{r' - r + L}{2}. \qquad \textbf{(15.)}$$

$$z = \frac{r + r' - L}{2}. \qquad \textbf{(16.)}$$

The value of L, if not already known, may be calculated from the known size and length of the wire.

EXAMPLE.—A test was made for a fault where no good wire was available. The resistance measured at the first station was 600 ohms, and that at the second station 630 ohms, and the resistance of the line was 1,150 ohms. What was the resistance to the fault from the first station? from the second station? What was the resistance of the fault?

SOLUTION.— $r = 600$, $r' = 630$, $L = 1{,}150$.

$$z = \frac{600 + 630 - 1{,}150}{2} = 40. \quad \text{Ans.}$$

$$x = \frac{600 - 630 + 1{,}150}{2} = 560. \quad \text{Ans.}$$

$$y = \frac{630 - 600 + 1{,}150}{2} = 590. \quad \text{Ans.}$$

EXAMPLES FOR PRACTICE.

1. A test for a fault was made upon an aerial line of 1,112 ohms resistance. The resistance of the line was 12.92 ohms per mile. The resistance measured at the first station, through the fault, was 630 ohms, and that at the second station 542 ohms. What was the resistance of the fault? How far was it from the first station, and how far from the second?

Ans. The resistance of the fault was 30 ohms. The distance from the first station to the fault was 46 miles 774 yards. The distance from the second station was 39 miles 1,108 yards.

2. A wire touched the ground so that there was no resistance z in the fault. A test was made at the station, and the unplugged resistance in the rheostat amounted to 326 ohms. What was the distance to the fault, the resistance of the wire being 16.1 ohms per mile?

Ans. 20 miles 438 yards.

243. The Varley Loop Test.—A better way of testing for a ground or cross on a line is by Varley's loop test, circuits for which are shown in Fig. 107, in which G is a reflecting galvanometer connected across the arms of a Wheatstone bridge in the ordinary manner; a and b are the ratio arms of the bridge, and k is the variable arm. $D E$ is the faulty line and F the location of the fault. $B E$ is a good line, the resistance of which is known. The two lines are connected together at E, and the ends of the loop so formed are connected across the terminals of the bridge, so

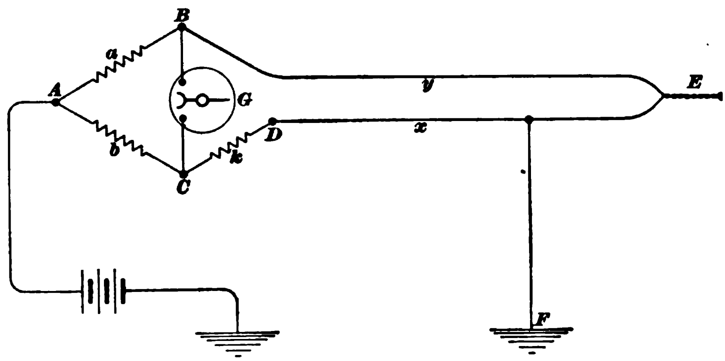


FIG. 107.

as to form the unknown resistance. The battery is connected between A and the ground. Call y the resistance of the loop from B to F, x that from D to F, and R the total resistance of the loop $= x + y$.

Then, when the bridge is balanced,

$$\frac{a}{b} = \frac{y}{k + x} = \frac{R - x}{k + x},$$

$$a k + a x = b R - b x,$$

$$a x + b x = b R - a k.$$

Hence, $$x = \frac{b R - a k}{a + b}. \qquad \textbf{(17.)}$$

It will be noticed that this is entirely independent of the resistance of the fault or of any earth-currents which may exist. Having found x, and knowing the resistance of the wire per foot, the distance to the fault is readily calculated.

If the faulty line is not grounded but is crossed with another, then the battery should be connected to the wire with which the faulty wire is crossed and not grounded, as shown in the figure.

EXAMPLE.—A ground occurs on one conductor of a cable 10,000 feet long, composed of three No. 10 insulated copper conductors. On testing, the bridge was balanced with the following resistances: $a =$ 10 ohms, $b = 1,000$ ohms, and $k = 1,642$ ohms. One good wire was used to complete the loop. Where is the ground, the resistance per thousand feet of the conductor being .9972 ohm at the temperature of the test?

SOLUTION.— $R = 2 \times 10 \times .9972 = 19.944$ ohms.

$$x = \frac{1,000 \times 19.944 - 10 \times 1,642}{10 + 1,000} = 3.4891 \text{ ohms.}$$

Distance from testing station $= \frac{3.4891}{.9972} \times 1,000 = 3,498.9$ ft. Ans.

A FEW FAULTS AND A FEW CAUSES.

244. In telephonic as well as in all other systems of electric connections, certain defects, called faults, will from time to time develop themselves, however well the apparatus may have been constructed and erected. *A very short list of only the most common* of these faults, with suggestions as to their origin, follows:

Can Not Ring or Receive a Ring.—Line or generator circuit may be open or short-circuited.

Can Hear But Can Not be Heard.—In such cases the trouble is usually with the battery or transmitter circuit. A careful examination of all connections therewith should be made.

Weak Ringing of Bells.—Loose connections, bad joints in line, or imperfect ground-connections at terminals of line in case a ground return is used.

Bell armature adjustment may be defective.

Hearing Bad.—Weak battery at the sending station or imperfect ground-connections at terminals of line.

Or, transmitter may be defective at sending station.

Or, receiver may be at fault at receiving station.

Rasping and Squeaky Noises in Receiver.—Loose connections in battery circuit or excessive battery power in primary circuit. This trouble may also be caused by a buckled diaphragm in the receiver or by particles of foreign substance lodging between diaphragm and pole-piece of receiver.

Or, position of diaphragm not correct, should be .015 inch from the magnet.

Or, magnet may be weak. It should hold the diaphragm on edge.

Can Ring Both Directions But Can Not Hear at Either Station.—This may result from imperfect receiver cord or disconnected wire in receiver or transmitter.

Bell Rings Frequently Without Apparent Cause.—Line-wire swings across telegraph or other lines.

Badly soldered joints, loose connections at binding-posts, dirty contacts, and broken battery jars are frequent causes of trouble; all connections must be free from corrosion.

GROUND WIRES.

245. The most prolific source of trouble on grounded telephone-lines is bad ground wires. Dry earth, sand, gravel, etc., are not conductors of electricity. Contact must be made with damp earth. It is not sufficient to put the ground wire a few feet in the earth, where in the summer the ground becomes dry, and in winter the earth freezes around and below it.

Weak bell ringing and faint talking will frequently be caused by bad grounds, when the cause is attributed to faulty bells, microphones, or hand telephones.

Dry ice is an excellent insulator, and a ground wire in frozen earth is absolutely worthless.

When practicable, terminate your ground wire in a good well, with a weight at the end to keep it in place. If you can conveniently reach a constant stream of water, that is still better. A cistern, of course, is of no use for this purpose, for it is merely a tight vessel for holding water, and the contents have no connection with the surrounding earth. Where driven wells are used, scrape the top of the well pipe, wrap your ground wire firmly around it, and solder it on. This makes a perfect ground-connection.

In cities or towns where gas or water pipes can be reached, make contact with either, preferably with water-pipes. If to a gas-pipe, it is well to connect a wire from the service-pipe outside of the meter to the house-pipe, thus bridging across the meter. Otherwise, should the meter be removed for repairs or other cause, your line is opened.

It is not well, generally, to attach to a gas-pipe that is also used for a telegraph ground, as an imperfect joint in the gas-pipe, beyond the point of contact, would cause a portion of the telegraph current to set back and find a ground through your wire, annoying you with telegraph signals in your telephones.

PUTTING UP TELEPHONES.

246. The chief points to be observed in putting up a wall telephone set are to place it against a solid wall, so that no ordinary vibration of the building shall affect it, and in such a position as regards neighboring objects that the receiver and bell crank will be got at easily, and as regards height from floor so that those who will require to use it most can speak to the transmitter without undue stretching or stooping. A brick and plaster wall should be plugged with four taper wooden plugs, about 3 inches long and 1 inch in diameter at the thick end, hammered flush with the wall, to receive the screws that go through the four corners of the backboard. The user of the telephone will generally indicate the most convenient place for it, and his wishes should of course be respected, provided that the instrument will have a fair chance in the position selected. If it is obviously unsuitable, this should be pointed out and explained, in the interest of the customer himself. Any situation that will cause the telephone to be in the way of office traffic should be avoided, both because of the risk of the instrument getting damaged by accidental collision and because of annoyance to any one talking of having people pass close by frequently. The best place for an office telephone is in a small closet or space partitioned off for that purpose.

A SERIES

OF

QUESTIONS AND EXAMPLES

RELATING TO THE SUBJECTS
TREATED OF IN THIS VOLUME.

It will be noticed that the various Question Papers that follow have been given the same section numbers as the Instruction Papers to which they refer. No attempt should be made to answer any of the questions or to solve any of the examples until the Instruction Paper having the same section number as the Question Paper in which the questions and examples occur has been carefully studied.

TELEPHONY.

(PART 1.)

EXAMINATION QUESTIONS.

(1) What is acoustics?

(2) (*a*) What is frequency? (*b*) How is it often misused?

(3) (*a*) What are the sounds made by the vocal organs in producing speech termed? (*b*) Are these sounds produced by simple or complex waves?

(4) (*a*) Is the current set up in the secondary winding of an induction-coil, in the primary of which is a microphone transmitter and battery, an alternating one, or does it merely undulate without changing its direction? (*b*) Why?

(5) (*a*) What effect has the shifting of the phase relations between two simple waves upon the complex wave of which they form parts? (*b*) When the components of a complex electrical wave produced by a telephone are shifted with respect to their phases, what would be the result on the sound produced by the receiver? (*c*) Why?

(6) (*a*) What methods are successfully used for maintaining permanent adjustment between the diaphragm and pole-pieces in receivers? (*b*) Name some receivers exemplifying each method.

(7) Give two definitions for sound.

(8) Why is it that simple harmonic motion, although taking place in a straight line, is often expressed in terms of angular measure?

(9) In what respect did the method of telephonic transmission produced by Bourseul and carried out by Reis lack the elements of success?

(10) What notable advance in the science of telephony was made (*a*) by Professor David E. Hughes? (*b*) by Edison? (*c*) by Berliner?

(11) (*a*) What effect does the presence of self-induction have on the current flowing in a circuit? (*b*) What effect does capacity have? (*c*) Can electrostatic capacity neutralize the effects of self-induction? (*d*) Under what conditions?

(12) How are permanent magnets formed?

(13) In what direction do the particles of air forming part of a sound wave vibrate with respect to the direction in which the wave is moving?

(14) What is Fourier's theorem?

(15) Why did Bell's improved apparatus require no battery?

(16) (*a*) Name four theories that have been proposed to account for the action of the microphone, describing each briefly. (*b*) Which theory is probably the true one?

(17) (*a*) What effect does resistance alone have upon telephonic transmission? (*b*) What are the effects of self-induction? (*c*) What are the effects of capacity?

(18) (*a*) What iron is best adapted for the cores of receiver and ringer coils? (*b*) Why?

(19) What is simple harmonic motion?

(20) (*a*) How low a rate of vibration is capable of producing the sense of a continuous sound on the average human ear? (*b*) How high a rate of vibration?

(21) (*a*) Does a magneto-transmitter generate alternating currents or simply undulating currents which do not change their directions? (*b*) Why?

(22) Why is it advantageous to use a microphone transmitter in a local circuit including the primary of an induction-coil rather than directly in the line-wire?

(23) (*a*) Into what classes may commercial telephone receivers be divided? (*b*) Which are used to the greatest extent?

(24) (*a*) Why are magneto-transmitters not generally used? (*b*) What advantages are possessed by the magneto-transmitter?

(25) How is the amplitude of vibration defined in this Paper?

(26) (*a*) In what respects do sounds differ from each other? (*b*) Define each of the characteristics by which we are enabled to distinguish different sounds.

(27) (*a*) Are the currents in the primary circuit of an ordinary telephone alternating, or do they merely fluctuate without changing their direction? (*b*) Why?

(28) What would the exact telephonic reproduction of speech involve, and why is it an impossibility?

(29) What are some of the mechanical defects to be guarded against in telephone receivers?

(30) (*a*) Into what classes may microphone transmitters be placed? (*b*) Give one or more examples of commercial transmitters in each class.

(31) (*a*) How many and what kind of cells are ordinarily used with a Blake transmitter? (*b*) What happens when too great a battery power is used?

(32) What precautions are taken to prevent packing?

(33) (*a*) In what manner are electromotive forces set up in the magneto-generator? (*b*) Are the currents in the armature of a magneto-generator direct or alternating?

(34) How are bars usually permanently magnetized?

(35) (*a*) Describe the generator shunt of the Western Telephone Construction Company; (*b*) of the Williams Electric Company; (*c*) of the Western Electric Company; (*d*) of the Holtzer-Cabot Company.

(36) (*a*) Describe the Warner hook switch. (*b*) Mention some points in defective design that are avoided in the Warner switch.

(37) (*a*) Describe the usual method of mounting the transmitter coil in the base of the transmitter arm. (*b*) How are the connections made from the transmitter and coil to the other parts of the apparatus?

(38) (*a*) If a simple sine-wave alternating current having a frequency of 300 flows in a circuit whose self-induction is 8 henrys, what must the electrostatic capacity of that circuit be in order to cause neither an angle of lag nor lead between the current and the electromotive force? (*b*) Why can not the phase angle of all overtones be reduced to zero, causing, therefore, no displacement of one relatively to another, and consequently not reducing the clearness of the reproduced sound?

(39) What serious disadvantage have most transmitters of the multiple-electrode type?

(40) Describe the construction of an ordinary telephone induction-coil.

(41) Is the current sent out by a magneto-generator alternating, or does it fluctuate without changing its direction?

(42) Why are laminated cores for generator armatures better than solid cast cores?

(43) What is there peculiar in the driving-gear of the Williams generator?

(44) (*a*) Do the talking circuits of a series instrument differ from those of a bridging instrument? (*b*) Describe briefly the circuits of a bridging instrument.

(45) (*a*) With what transmitter is the Fuller cell frequently used? (*b*) What are its advantages? (*c*) What are its disadvantages?

(46) (*a*) What is impedance? (*b*) What is the impedance of a circuit possessing resistance and self-induction?

(*c*) What is the impedance of a circuit possessing resistance and capacity? (*d*) What is the impedance of a circuit possessing resistance, self-induction, and capacity?

(47) (*a*) What is probably the best and most extensively used transmitter? (*b*) By whom was it invented? (*c*) By what companies and for what purposes is it used?

(48) Does an induction-coil that will give the best results with one transmitter usually give similar results with another?

(49) Describe the action of the polarized bell (*a*) when its coils are traversed by currents in either direction; (*b*) when traversed by alternating currents.

(50) (*a*) What form of current wave has been found most suitable for ringing purposes? (*b*) What effect does the shape of the pole cheeks of the armature have on the form of current wave?

(51) (*a*) Describe the Williams-Abbott ringer. (*b*) What advantages are secured by this construction?

(52) (*a*) How should the various wires forming the circuits of a telephone be permanently connected? (*b*) How should temporary connections be made? (*c*) How are flexible connections made to the cover of the box?

(53) (*a*) Under what condition is the use of dry batteries advantageous? (*b*) Are they as reliable as wet cells, and why?

(54) What is there peculiar in the construction of the Colvin transmitter?

(55) Into what two general classes may calling apparatus be divided?

(56) (*a*) What is a generator shunt? (*b*) Why are shunts used around generator armatures?

(57) (*a*) What is the voltage of an ordinary magneto-generator when turned at average speed? (*b*) What is the resistance of the armature winding of such a generator, and with what size of wire is it wound? (*c*) What is the usual ratio of the driving-gear on generators?

(58) Why should not cast iron be used in ringer frames?

(59) (*a*) Describe the construction of a good receiver cord. (*b*) How are the cord tips fastened in place?

(60) What three kinds of variations may be used to produce a current which will transmit articulate speech?

(61) What are the causes of packing in granular-carbon transmitters?

(62) Why are vibrating bells actuated by batteries not more generally used in telephone work?

(63) What precaution should be taken in tempering permanent magnets for generators?

(64) (*a*) What is the difference between a polarized bell for a series telephone and one for a bridging telephone? (*b*) Why should the series bell have a low coefficient of self-induction and the bridging a high coefficient?

(65) (*a*) What are the functions of the hook switch? (*b*) Why is it desirable to have the changes in circuit brought about automatically?

(66) (*a*) What wood is found most desirable for telephone cabinets and boxes? (*b*) Describe a good form of battery-box and the method for attaching it to the back-board. (*c*) What advantages arise from this construction of battery-box?

(67) (*a*) In a magneto-receiver, why can not the amount of motion of the diaphragm be indefinitely increased by indefinitely increasing the strength of the permanent magnet? (*b*) Why is a damping finger of some sort necessary in a microphone transmitter, but not in a magneto-instrument?

TELEPHONY.

(PART 2.)

EXAMINATION QUESTIONS.

(1) (*a*) What is a telephone exchange? (*b*) Into what three general classes may telephone systems be divided?

(2) By what means are calls usually received in telephone exchanges?

(3) In making the ground connections of telephone-lines at the central office, is it necessary to run each line-wire to a separate ground, or not?

(4) What are the general requirements of switchboard drops?

(5) Why can not changes in temperature or in the moisture of the atmosphere affect the adjustment of the Warner tubular drop?

(6) Describe a simple and reliable method of clamping flexible cords to the framework of switchboards.

(7) What are the disadvantages of the grounded-line system?

(8) (*a*) For what purpose is the night alarm used in telephone exchanges? (*b*) Describe its operation.

(9) (*a*) How does a common-return system differ from a grounded system? (*b*) Can the same switchboard and telephone apparatus be used for common-return systems as for grounded systems?

(10) Mention three remedies that may be applied to prevent cross-talk between switchboard drops.

(11) Mention three types of switchboard drops that are enclosed in a magnetic shield.

(12) (*a*) Describe several forms of cord connectors for attaching the conductors of the cord to the stationary portions of the switchboard. (*b*) How may the cord terminals be prepared for soldering to connectors?

(13) (*a*) Describe the common-return system. (*b*) What advantages does it possess over the grounded system?

(14) How does the operator at a telephone exchange connect her telephone set with the line of a calling subscriber?

(15) (*a*) What is a metallic-circuit jack? (*b*) How does a metallic-circuit jack differ from a jack for common-return or grounded lines?

(16) Describe the phenomenon of cross-talk between switchboard drops.

(17) (*a*) Describe a double-magnet drop that is sometimes used on long-distance lines. (*b*) What advantages has this drop? (*c*) What disadvantages has it?

(18) What is a self-restoring switchboard drop?

(19) (*a*) What is the only complete remedy for all disturbances on telephone-lines? (*b*) How does a metallic-circuit system differ from a common-return system?

(20) Give a simple sketch of a spring-jack and plug for common-return or grounded systems.

(21) Describe the circuits of a simple metallic-circuit switchboard.

(22) Describe the Warner tubular drop.

(23) (*a*) Describe a form of flexible switchboard cord that has not given very satisfactory service. (*b*) Describe the form that is now generally used.

(24) (*a*) Into what two classes may self-restoring switchboard drops be divided? (*b*) Mention one or more examples of each type.

(25) (*a*) Into what two classes may switchboards be divided? (*b*) To which of these classes does the great majority of switchboards belong? (*c*) Why is this so?

(26) (*a*) Describe the circuits of a simple switchboard for grounded circuits. (*b*) Describe the operation of this switchboard.

(27) What is a clearing-out drop?

(28) How is cross-talk prevented between drops of the Warner type?

(29) In what respects do switchboard cords often give trouble?

(30) (*a*) What are self-restoring drops? (*b*) Describe the operation of an electrically restoring drop.

(31) Describe the operation of the Western Telephone Construction Company's self-restoring drop.

(32) Mention a method by which an operator's telephone circuit can be connected to a line without the use of special listening keys.

(33) What advantage has a jack of the form shown in Fig. 49 over a jack of the form shown in Fig. 48?

(34) How is the clearing-out signal given at the outgoing *B* board in the express system?

(35) (*a*) What is the difference between the series-multiple switchboard and the branch-terminal multiple switchboard? (*b*) What are the advantages and disadvantages of each?

(36) Describe the operation of the American Electric Telephone Company's self-restoring switchboard drop.

(37) How is the ringing of a subscriber sometimes accomplished by a special jack without the use of ringing keys?

(38) (*a*) Describe the method of signaling from the subscriber to the central office, in the express system. (*b*) What desirable results does this method bring about?

(39) Describe the use of phonographs as labor-saving devices in the express system.

(40) Describe the operation of testing on the series-multiple board.

(41) What connections are made in each of the four positions of the O'Connell listening and ringing key?

(42) When exchanges must be equipped for a number of subscribers greater than four or five hundred, what two general methods may be resorted to?

(43) In the express system of Savin & Hampton, what are the duties of the *A* and *B* operators?

(44) (*a*) What advantage does the multiple switchboard have over all forms of divided-switchboard systems? (*b*) What disadvantage has it?

(45) (*a*) Describe the test circuits in the branch-terminal multiple board. (*b*) What is the function of the auxiliary contact on the plugs in the branch-terminal system?

(46) (*a*) With the Cook key, what connections are made with lever *d*, (1) in the right-hand, (2) in the middle, and (3) in the left-hand positions? (*b*) State one advantage of this over the O'Connell key for ring-up subscribers.

(47) Mention several forms of transfer systems.

(48) Describe the circuits of the *A* operator's board in the express system.

(49) What is the one feature that distinguishes multiple boards from all other forms of boards?

(50) Describe by the aid of a simple sketch the essential features and arrangement of parts in the plugs and spring-jacks used in the branch-terminal switchboards.

(51) Describe the construction and operation of the American Electric Telephone Company's combined listening and ringing key.

(52) (*a*) Describe the transfer circuits of the Western multiple-transfer system. (*b*) Why is this system called a multiple system? (*c*) Is it practically a multiple switch-board?

(53) How is the clearing-out signal given at the incoming *B* board in the express system?

(54) Why is some form of busy test necessary in multiple switchboards?

TELEPHONY.

(PART 3.)

EXAMINATION QUESTIONS.

(1) What are some of the advantages to be derived from a complete centralization of batteries and generators in telephone exchanges?

(2) What are the principal points of difference in the Dean common-battery system and the systems of Stone and Hayes?

(3) (*a*) Describe the circuits of a complete Hayes common-battery system as adapted for small exchanges. (*b*) Describe its operation, including the calling of the operator, the connection of the subscribers, and the final clearing-out signals and disconnections of subscribers.

(4) (*a*) What wire is it best to use in forming switchboard cables? (*b*) Why is it well to use tinned wire?

(5) What is a sneak current, and wherein lies its danger?

(6) Name several common methods of driving calling generators at central offices.

(7) (*a*) What was the earliest attempt at centralizing transmitter batteries? (*b*) What disadvantage did this have?

(8) (*a*) Describe the Dean common-battery system. (*b*) Why are the impedance coils *I* and *I'* (see Fig. 8) bridged across the line circuit?

(9) (*a*) What are supervisory signals? (*b*) What kind of signals are used for this purpose?

(10) (*a*) Make sketches showing the proper and the improper method of lacing cables. (*b*) Why is the proper method the more desirable?

(11) What are the purposes of a distributing board?

(12) For what are motor generators used in telephone work?

(13) What kind of annunciators are ordinarily used on series and bridged party lines, and how should such line circuits be arranged at the switchboard?

(14) (*a*) Describe the simplest method of associating a lamp signal with the line circuit in a telephone exchange. (*b*) What disadvantages has this system? (*c*) What advantages? (*d*) Under what conditions may it be used to best advantage?

(15) Describe two methods of associating supervisory signals with the cord circuits of the switchboard.

(16) Why should the use of acid be avoided in soldering switchboard connections?

(17) For what purpose is an intermediate board used?

(18) (*a*) Why are cut-outs desirable in the charging circuit of a storage-battery? (*b*) Describe one form of such cut-out.

(19) (*a*) Describe the Stone system of supplying transmitter current from a single battery. (*b*) Why are the impedance coils used in series with the battery? (*c*) Why is the circuit formed by the two connected subscribers' lines kept free from impedance coils?

(20) What is the most approved method of associating a lamp signal with a telephone-line?

(21) Upon what conditions does a line test busy in the multiple-board common-battery system shown in Fig. 12?

(22) Describe the saw-tooth form of telephone lightning-arrester.

(23) (*a*) What are jumper wires? (*b*) What kind of wire is best adapted for this purpose?

(24) What precaution should be taken in connecting up the charging circuit of a storage-battery ?

(25) (*a*) Describe the Hayes system of centralized transmitter battery. (*b*) How does it differ from the Stone system ? (*c*) What are the functions of the repeating coils ?

(26) What is a line cut-off relay ?

(27) Why is it important to perform the wiring of switchboards and exchanges in a systematic manner ?

(28) Describe two forms of current arresters for telephone apparatus, depending for their action upon the heating effect of a current.

(29) What form of calling generator is commonly used at the central office of small exchanges ?

(30) What is probably the easiest and most reliable method of determining the polarity of the terminals of the charging generator ?

(31) (*a*) Of what does the solution for an ordinary form of storage-battery consist ? (*b*) Describe the mixing of the solution. (*c*) Why should the acid be poured into the water instead of the water into the acid ?

(32) (*a*) What is a party line ? (*b*) Why is not a line having two stations only, strictly speaking, a party line ?

(33) (*a*) How should series instruments be connected to a line-wire ? (*b*) How should bridging instruments be connected to a line-wire ?

(34) Describe the circuits and operation of the Scribner lock-out system for party lines.

(35) How do the relays in the various stations of the Barrett-Whittemore-Craft party-line system differ from each other ?

(36) (*a*) Where are the fuses used besides in the exchange and sometimes at the subscriber's telephone ? (*b*) Why are the fuses enclosed in insulating tubes better than exposed fuses ?

(37) How would you determine when a storage-battery needs recharging? Also, when it is fully charged?

(38) (*a*) Into what two general classes, with reference to signaling, may party lines be divided? (*b*) How may each of these general classes be subdivided?

(39) (*a*) In what respect does the bridged ringer differ from that used in the series telephone? (*b*) In what respect does the bridged generator differ from that used in the series telephone? (*c*) Why is it bad policy to use high-wound induction-coils on bridged lines?

(40) (*a*) What is the step-by-step method of signaling on party lines? (*b*) What difficulties are met in this system?

(41) (*a*) Describe the lock-out mechanism of the Barrett-Whittemore-Craft party-line system. (*b*) What releases the mechanism at the station of the subscriber who is being called?

(42) What form of switching apparatus is sometimes used in house or intercommunicating systems instead of the rotary switch-lever?

(43) Name several ways of charging storage-batteries.

(44) Describe the circuits of a series instrument.

(45) How may calling in one direction only on party lines be accomplished?

(46) (*a*) Describe the fundamental principles of harmonic selective signaling on party lines. (*b*) What are the faults of this system?

(47) (*a*) How is a party line operating on the Barrett-Whittemore-Craft system connected with the central office drop and jack? (*b*) How is the drop at the central office thrown by the removal of the subscriber's receiver from the hook? (*c*) Why does not the current from the battery B'' (see Fig. 56) operate the switchboard drop under normal conditions?

(48) Describe the Carty bridging-bell system for party lines.

(49) Describe the methods of furnishing current to the operator's transmitter, in which gravity batteries are used.

(50) What are the principal objections to the connection of telephone instruments to a party line in series?

(51) What is a lock-out system for party lines?

(52) (*a*) Describe the circuits of the Hibbard party-line system. (*b*) Describe its operation. (*c*) For how many stations is this system adapted?

(53) (*a*) What is a house system? (*b*) By what other names is it frequently called?

(54) (*a*) Describe a method of supplying current to operators' transmitters from a single storage-battery. (*b*) What precautions must be taken in using this system for the prevention of cross-talk between the operators' circuits?

(55) (*a*) To what resistance are the ringer magnets of telephones designed to be used on series party lines usually wound? (*b*) To what resistance are the generators for these instruments usually wound? (*c*) Why is it well to use low-wound ringers and high-wound generator armatures on series lines?

(56) Upon what principle does the Barrett-Whittemore-Craft system of selective signaling on party lines operate?

(57) (*a*) What is the disadvantage of the ordinary house system? (*b*) How may this disadvantage be avoided?

TELEPHONY.

(PART 4.)

(1) What effect does resistance alone have on telephone transmission?

(2) (*a*) What is the K. R. law? (*b*) Why has it fallen into some disrepute?

(3) (*a*) Describe the phenomenon of electrostatic induction between two parallel telephone-lines. (*b*) How may the tone produced by induction from a lighting or power circuit be distinguished from that from a telegraph-wire or from another telephone-wire?

(4) Describe the method of using a receiver when testing for crosses in cables.

(5) Name some of the conditions that must be considered in selecting the route for a pole line.

(6) Describe the usual method of laying out the positions for poles after the general route of the pole line has been determined.

(7) Give the dimensions of standard cross-arms and of telephone cross-arms.

(8) (*a*) Under average conditions, how many 6-foot pole holes can one man dig in a day? (*b*) What tools are most used in digging the pole hole?

(9) How may the lower ends of guy wires be secured?

(10) (*a*) What is a mil? (*b*) What is a circular mil? (*c*) Why is circular measure convenient in expressing the sizes of wire?

(11) (*a*) In what part of a telephone circuit is most of the self-induction concentrated? (*b*) How much greater is the apparent resistance of a metallic-circuit copper wire than the actual resistance?

(12) (*a*) What is the insulation resistance of a line? (*b*) How is the insulation resistance per mile determined from the total insulation resistance?

(13) (*a*) What is cross-talk? (*b*) What particular fact did the experiments of Mr. John J. Carty establish in regard to cross-talk?

(14) (*a*) What is the common-return system? (*b*) In what respect is it better than a grounded system?

(15) (*a*) What kinds of wood are commonly used for telephone poles? (*b*) What is the approximate life of each kind? (*c*) Which is probably the best wood, all things considered?

(16) What precautions must be taken where it is necessary to span a river by aerial lines?

(17) (*a*) Describe two methods of attaching cross-arms to poles. (*b*) Which is considered the best practice?

(18) Describe the method of raising poles.

(19) Of what are guy wires composed?

(20) What is the area in circular mils of a round wire having a diameter of 80.808 mils?

(21) What is the most serious drawback to long-distance telephony?

(22) What are some of the sources of disturbing noises in telephone-lines?

(23) Describe two of Mr. Carty's experiments by means of which he demonstrated that electrostatic induction, rather than electromagnetic induction, was the cause of most cross-talk.

(24) Describe how, in a common-return system, the return circuit from one line may be made through all the other lines in multiple.

(25) What is the usual requirement in regard to the dimension of poles of various lengths?

(26) (*a*) What is meant by grading a line of pole tops? (*b*) Describe how it may be accomplished. (*c*) What are the evil effects due to improper grading of pole tops?

(27) (*a*) What are cross-arm braces? (*b*) Why are they used? (*c*) How are they secured to the cross-arms and pole?

(28) (*a*) How is a pole held in a vertical position, after being raised, while the tamping is being done? (*b*) What precaution should be taken in filling in around the poles?

(29) (*a*) For what purpose are manholes used in conduit work? (*b*) How far apart are they placed? (*c*) Where are they preferably placed?

(30) Find the circular mils of a wire $\frac{1}{8}$ inch in diameter.

(31) Distinguish between local and distributed capacity.

(32) Which source of induction is the most troublesome in telephone-lines, electromagnetic or electrostatic?

(33) How may cross-talk be overcome on grounded telephone-lines?

(34) Describe two methods of connecting a grounded circuit to a metallic circuit, stating the advantages and disadvantages of each.

(35) In what cases may poles having tops less than 7 inches in diameter be used?

(36) (*a*) In unloading poles along a selected route, should the butts be laid up hill or down? (*b*) Why?

(37) (*a*) What is the best wood for brackets and pins? (*b*) How is a pin secured in a cross-arm? (*c*) How is the insulator secured on a pin?

(38) (*a*) When are special pole foundations necessary? (*b*) How may they be made?

(39) Discuss the relative merits of porcelain and glass for line insulators.

(40) What is the diameter of a wire having a cross-sectional area of 10,383.02 circular mils?

(41) Why is it that although the speed at which an electric wave travels is over a hundred thousand miles per second, an electric impulse may flow over a line circuit at a much slower rate than this?

(42) Describe the phenomenon of electromagnetic induction between two parallel telephone-lines.

(43) How may cross-talk and other forms of induction be avoided in metallic-circuit lines?

(44) (*a*) Describe the construction of a repeating coil. (*b*) Why are the iron ends of a repeating coil bent around the outside of the coil, so as to encase it in a sheet of iron?

(45) (*a*) What precautions are sometimes taken to prolong the life of poles? (*b*) What is the wind-and-water line?

(46) How should the gains and roofs of poles be treated after being cut?

(47) (*a*) For average conditions, how deep should pole holes be made? (*b*) What conditions may render other depths of pole holes necessary?

(48) (*a*) What is a **Y** guy? (*b*) Why is it better to use the **Y** guy than to attach the guy wire to the pole at a single point?

(49) (*a*) How are the various sizes of wires usually designated? (*b*) What gauge is most commonly used for copper wire? (*c*) What for iron wire?

(50) What simple rule connects the various sizes of wire in the B. & S. gauge?

(51) Mention a few facts concerning wires in the B. & S. gauge that may be conveniently used in rough calculations.

(52) What is Matthiessen's standard?

(53) (*a*) What are the terms by which the various grades of iron wire are distinguished? (*b*) Describe each of these grades.

(54) Why is it that wire should not be drawn as tight in the summer as in the winter?

(55) (*a*) Into what two classes may paper cables be divided? (*b*) What advantages has each?

(56) How are cables supported on poles?

(57) (*a*) Describe the manufacture of the sections of the cement-arch conduit. (*b*) How is this conduit laid?

(58) (*a*) Describe the operation of rodding. (*b*) How are cables drawn into conduits?

(59) (*a*) Why is it that submarine telephony is not now practicable over long distances? (*b*) What is the main problem to be solved before transoceanic transmission can be accomplished?

(60) (*a*) How may wires be identified at one end of a cable? (*b*) How may wires be identified at intermediate points in a cable without cutting them?

(61) In taking the galvanometer constant, a deflection of 324 scale divisions was obtained, using a $\frac{1}{10}$-megohm box and a shunt having a multiplying power of 1,000. What was the constant?

(62) (*a*) What is the meaning of the term "weight per mile-ohm," or "mile-ohm"? (*b*) How may the weight per mile-ohm be used in measuring the percentage conductivity of a wire?

(63) (*a*) What breaking strength is usually required in specifications for hard-drawn copper wire? (*b*) What mechanical properties should be required in specifications for hard-drawn copper wire?

(64) (*a*) In testing the galvanizing of a sample of iron wire, the sample was immersed three times in a saturated solution of copper sulphate, each immersion lasting one minute, and the wire thoroughly wiped off after each immersion. After the third immersion, a deposit of copper appeared on the surface of the wire. What conclusion should be reached concerning this wire? (*b*) Why?

(65) (*a*) Describe two methods of splicing bare wire. (*b*) In soldering an American wire joint, should the solder be applied over the whole joint or not, and why?

(66) (*a*) What precautions should be taken before splicing two dry-core cables together? (*b*) How should these precautions be carried out?

(67) Describe the method of stringing cables after the supporting wire is in place.

(68) (*a*) What advantages has the vitrified clay conduit? (*b*) Which is considered better, a single-duct section or a multiple-duct section? (*c*) Why?

(69) How are wires led from underground conduits to overhead circuits?

(70) What are the principal instruments used in making rough tests of telephone lines and circuits?

(71) What is the most satisfactory instrument for the measurement of all ordinary resistances?

(72) After the constant of a galvanometer has been determined, and after the deflection produced by passing the battery current through the galvanometer and the insulation resistance to be measured has been noted, describe the calculation of the insulation resistance.

(73) If the weight per mile-ohm of pure copper at a certain temperature is 869 and the weight per mile-ohm of a certain quality of commercial copper at the same temperature is 885, what is the percentage conductivity of the commercial copper?

(74) What is the approximate resistance per mile of a good quality of No. 8 B. W. G. iron wire?

(75) What are the advantages and disadvantages of aluminum as a line conductor?

(76) (*a*) When it is necessary to run a great number of wires in a limited space, what construction is usually adopted? (*b*) How is induction eliminated in telephone cables? (*c*) Can grounded-circuit telephone-lines be worked successfully through cables?

(77) Describe the making of a splice in a dry-core telephone cable.

(78) Why should some slack be left in each length of telephone cable?

(79) How is the alinement preserved in laying a vitrified-clay conduit?

(80) (*a*) At what points on underground cables is the sheath liable to injury by electrolysis? (*b*) How may the danger points be located?

(81) Why may not the magneto testing set be implicitly relied upon in testing out long circuits either for continuity or grounds?

(82) (*a*) What two types of galvanometers are used for making accurate tests on lines and cables? (*b*) Name the advantages and disadvantages of each.

(83) Describe a test for locating crosses or grounds on telephone-lines when no good wire is available.

(84) What is the weight per mile of a copper wire having a diameter of 71.962 mils?

(85) What advantages has copper over iron wire for telephone work?

(86) (*a*) Where only a few wires are to be strung on poles, what method is usually employed for paying out the wire? (*b*) Describe the use of a running board.

(87) What are the advantages and disadvantages of the rubber-covered telephone cable?

(88) For what are cable terminals used?

(89) (*a*) What is the cheapest form of conduit for underground cables that allows of the drawing in or out of cables? (*b*) What disadvantages are sometimes urged against this conduit?

(90) Give the formula and describe the method of mixing the concrete and mortar for conduit work.

(91) What methods should be used to prevent the injury of cable sheaths by electrolysis?

(92) What are the advantages of the telephone receiver as a rough testing instrument?

(93) Describe the general method of measuring insulation resistance with a galvanometer.

(94) Describe the Varley loop test for locating crosses on telephone-lines.

A KEY

TO ALL THE

QUESTIONS AND EXAMPLES

CONTAINED IN THE

EXAMINATION QUESTIONS

INCLUDED IN THIS VOLUME.

The Keys that follow have been divided into sections corresponding to the Examination Questions to which they refer, and have been given corresponding section numbers. The answers and solutions have been numbered to correspond with the questions. When the answer to a question involves a repetition of statements given in the Instruction Paper, the reader has been referred to a numbered article, the reading of which will enable him to answer the question himself.

To be of the greatest benefit, the Keys should be used sparingly. They should be used much in the same manner as a pupil would go to a teacher for instruction with regard to answering some example he was unable to solve. If used in this manner, the Keys will be of great help and assistance to the student, and will be a source of encouragement to him in studying the various papers composing the Course.

TELEPHONY.

(PART 1.)

(1) That branch of physics which treats of sounds and sound waves.

(2) (*a*) The frequency of vibration is the number of complete vibrations or cycles occurring in one second.

(*b*) The mistake is often made by referring to the frequency as the number of half vibrations that occur in a second, thus giving twice the proper value to the frequency.

(3) (*a*) Articulate speech.

(*b*) Exceedingly complex.

(4) (*a*) It is alternating.

(*b*) The lines of force set up in the core of the induction-coil remain in the same direction, although they increase and diminish in number according to the strength of the current in the primary circuit. Increasing the number of lines of force will induce a current in the secondary in one direction, while decreasing the number will induce a current in the other direction, providing the lines of force remain in the same direction. Therefore, the secondary current flows in one direction while the primary current is increasing, and in the other direction while the primary current is decreasing. It is, therefore, alternating.

(5) (*a*) It alters the form of the wave.

(*b*) The timbre or quality of the sound would be altered.

(*c*) Because the wave form is altered.

(6) (*a*) The use of metal-head receivers, by which the permanent magnet, the pole-pieces, the coils, and the diaphragm are all firmly secured together by a metal having very nearly the same coefficient of expansion as steel. Another method is to secure the permanent magnet to the shell at a point near the diaphragm, so that differences in the contraction and expansion between the shell and the magnets will produce little or no effect.

(*b*) The Holtzer-Cabot receiver and the Ericsson receiver are examples of the metal-head construction, while the Pony receiver of the American Bell Telephone Company and the receiver of the Western Telephone Construction Company are examples of the latter construction.

(7) First, sound is a sensation produced on the auditory nerves when excited by the proper vibrations. Second, sound is a physical disturbance capable of stimulating the auditory nerves to produce the sense of hearing.

(8) The connection between simple harmonic motion and circular motion is very close. Simple harmonic motion occurs in a straight line, but it always represents the motion of the projection of a point traveling with a uniform motion in a circular path. It is much easier to deal with a uniform motion in a circular path than it is to deal with a variable motion in a straight path, and therefore we refer to the position of the point moving with simple harmonic motion by means of the position of the corresponding point of which it is the projection, and which is moving with a uniform motion on the circumference of a circle. It is most convenient to designate the position of a point on a circle by angular measure, that is, by means of the angle through which at a given time it has passed; and therefore we may, and usually do, refer to the position of the projection of the point which is moving on the circle by means of the angle through which the point itself has passed.

(9) They worked upon the make-and-break principle, instead of upon the principle of maintaining the circuit constantly closed and varying its resistance in accordance with the sound waves.

(10) (*a*) Hughes showed that the best conditions for microphonic action were when the contact between the electrodes was a loose one; that is, when there was but slight normal pressure between them.

(*b*) Edison was the first to use carbon as the electrodes of the microphone.

(*c*) Berliner is alleged to have invented the first transmitter using two electrodes in constant contact.

(11) (*a*) Self-induction tends to make a fluctuating or alternating current lag in phase behind the electromotive force which produces it.

(*b*) Capacity has the opposite effect, and tends to make the current lead the electromotive force in phase.

(*c*) Yes; under certain conditions.

(*d*) Electrostatic capacity can be made to neutralize self-induction for only one particular frequency at a time. If the frequency is changed, then a different amount of capacity must be introduced in order to neutralize a given self-induction.

(12) See Arts. **105** and **106**.

(13) In the same direction as the wave is moving. In distinction to this, the particles of water forming parts of a wave on the surface of the water move only up and down under the influence of the wave, and therefore at right angles to the line in which the wave is traveling.

(14) Fourier's theorem states that any complex periodic vibration may be considered as composed of a number of simple vibrations, these simple vibrations having frequencies equal to definite multiples of the frequency of the complex vibration; thus, a complex vibration having a frequency of 256 might be made up of a number of simple vibrations having frequencies equal to 256, 512, 1,024, 2,048, etc., vibrations per second.

(15) Because the magneto-telephone, when used as a transmitter, served in itself to generate the currents necessary for transmission. The transmitter acted as a dynamo to transform mechanical energy into electrical energy by electromagnetic induction.

(16) (*a*) First, that the changes in resistance of the microphone were due to the changes in the actual resistance of the carbon itself, these changes being brought about by the variable pressure. Second, that a film of air forms on the surfaces of the electrodes and prevents the actual contact between the electrodes, and that the changes in resistance are, therefore, due to the variable thickness of the film of air. Third, that the heating, caused by the current at the point of contact, served to still further lower the resistance of the contact, while the diminution in the heat, occasioned by the lessening of the current, caused the resistance of the carbon to rise and still further increase the resistance of the contact. Fourth, that the variable resistance is due almost entirely to changes in actual surface contact between the electrodes.

(*b*) The last named, that of variable surface contact.

(17) (*a*) Resistance serves only to cut down the current strength without altering the wave form. It reduces the loudness, but does not affect the clearness, of articulation.

(*b*) Self-induction tends to alter the wave form by causing the waves corresponding to the higher overtones to lag to a greater extent than those corresponding to the lower overtones and the fundamental. It therefore tends to impair the distinctness and also greatly cuts down the loudness of the sound, by introducing a high apparent resistance. (See Arts. **87** and **88.**)

(*c*) Capacity tends to produce a distortion of the wave form by causing an unequal shifting in phase of the waves corresponding to the various overtones. It also greatly cuts down the loudness of the sound received by absorbing the currents, which would otherwise pass over the line. This latter effect is due to the distributed electrostatic capacity of the line.

(18) (*a*) Swedish or Norway iron is the best material.

(*b*) Because these irons are very soft and do not become permanently polarized. Soft iron is much more susceptible to magnetic changes than is hard iron or steel.

(19) If a point moves with uniform velocity around the circumference of a circle, then the projection of that point on a diameter of the circle will move with simple harmonic motion. It may be defined as the movement of the projection on a fixed straight line of a point moving uniformly in a circular path.

(20) (*a*) About 32 complete vibrations per second.

(*b*) About 40,000 vibrations per second.

(21) (*a*) Alternating currents.

(*b*) Because the vibration of the diaphragm in the field of force of the magnet serves to alternately weaken and strengthen this field, according to whether the diaphragm is receding from or approaching the magnet pole.

Weakening the field in which a closed coil lies will set up an electromotive force in one direction, while strengthening the field will set up an electromotive force in the other direction, if the lines of force themselves remain in the same direction. Therefore, electromotive forces in alternately opposite directions are set up in the coil by every vibration to and fro of the diaphragm. These electromotive forces produce alternating currents if the coil of the transmitter forms a part of the closed circuit.

(22) There are two principal reasons, the first of which is that the low resistance of the local circuit allows a much greater current to flow through the transmitter with a given battery than if the transmitter and the same battery were placed in the line circuit; the second is that the changes in resistance that the transmitter is capable of producing will bear a much greater ratio to the total resistance of the circuit where it is placed in a low-resistance local circuit rather than in a high-resistance line circuit. The result of using a transmitter in a local circuit is that the transmitter is capable of producing larger changes in a current which is in itself greater than if in the line circuit.

(23) (*a*) Single-pole and double-pole.

(*b*) The greatest number of receivers in use now are of the single-pole type, but the double-pole receivers are rapidly coming into general use and will probably largely supersede the single-pole type.

(24) (*a*) Because the current produced by them is too feeble for any but comparatively short-distance work.

(*b*) No battery is required, and, moreover, these transmitters, when well designed, articulate well, preserving the quality of the tone with great accuracy.

(25) The amplitude of vibration is one-half the length of the path through which a point vibrates, or the maximum displacement from the center point.

(26) (*a*) Loudness, pitch, and timbre.

(*b*) Loudness is the intensity of sound, and depends on the amount of energy or amplitude of the vibrating body producing the sound. Pitch is that quality of sound which depends upon the rate of vibration. A tone is high or low according to whether the rate of vibration is high or low. Timbre is the quality of sound, and depends only on the form of the sound wave.

(27) (*a*) They fluctuate without changing their direction.

(*b*) Because the current from the local battery is always in the same direction, and the transmitter serves merely to vary the resistance of the local circuit. Therefore the current in the local circuit is correspondingly varied in strength, its direction remaining the same.

(28) The exact reproduction would involve the transmitting of the waves without diminution in amplitude, this being an impossibility because it would mean the transmission of electrical energy without loss of efficiency in the line or other parts of the circuit. It would involve the exact reproduction of the wave form, and this is an impossibility because self-induction or capacity is always present to some extent in the circuits and apparatus, and each of these tends to modify the wave form by giving greater prominence to some of the composite waves than to others, and to shift the component waves relatively to each other.

(29) One of the worst defects is the inability of some receivers to maintain a constant adjustment, changes in temperature, moisture, and mechanical shocks tending to alter the distance between the diaphragm and the pole-piece. The binding-posts in many receivers are not securely fastened to the shell, and soon become loose and either break off the leading-in wires within or twist in their seats so as to form a short circuit across the terminals. The use of imitation hard rubber in any of the principal parts of a receiver is a defect which should prohibit the purchase of such receivers.

(30) (*a*) Single-contact transmitters, multiple-electrode transmitters, and granular transmitters.

(*b*) The Blake is the most common example of the single-contact instrument; the Turnbull and Carbon Ball are good examples of the multiple-electrode type; while among the granular-carbon transmitters may be mentioned the solid-back, the Ericsson, and the Sutton.

(31) (*a*) One cell of the disque Leclanché type is usually sufficient to give the best results with the Blake instrument.

(*b*) If too great a battery power is used, a humming noise is produced in the receiver, due to a rapid vibration between the transmitter electrodes, caused by the alternate heating and cooling at the point of contact.

(32) The granules of carbon are made of substantially the same size, and in several forms of transmitters a space is provided around the electrodes for the reception of the granular carbon, this method being exemplified in the solid-back transmitter. In some cases, means are provided for mechanically agitating the granular carbon within the chamber, usually by rotating the transmitter. In the best forms of transmitters, great pains are taken to prevent the entrance of moisture from any cause whatever.

(33) (*a*) The electromotive forces are generated by means of electromagnetic induction, the number of lines of force passing through the coils of the armature being caused to rapidly vary by turning the coil in the field of force of a permanent magnet.

(*b*) The currents in the armature are alternating, because the number of lines of force passing through the coils are caused to rapidly vary from a maximum in one direction to a maximum in the other.

(34) By stroking them across the poles of a powerful electromagnet. It is sometimes done, however, by means of inserting the bars within coils carrying heavy currents, withdrawing them from these coils in such manner as not to neutralize the magnetism imparted.

(35) (*a*) See Arts. **189** and **190.**
(*b*) See Art. **193.**
(*c*) See Art. **200.**
(*d*) See Art. **198.**

(36) (*a*) See Art. **209.**
(*b*) See Art. **210.**

(37) (*a*) See Art. **238.**
(*b*) See Art. **239.**

(38) (*a*) When $\tan \Theta = 0,\ 2\pi n L = \frac{1}{2\pi n Q}$. See Art. **90**

$$(2 \times 3.1416 \times 300)\,8 = \frac{1}{(2 \times 3.1416 \times 300)\,Q};$$

$$\therefore\ Q = \frac{1}{8\,(2 \times 3.1416 \times 300)^2} = .00000003518 \text{ farad, or}$$

.03518 microfarad.

(*b*) See Art. **90.**

(39) They are inclined to rattle or break contact when subjected to loud noises, thus entirely destroying the quality of the transmitted tones and producing unpleasant noises in the receiver.

(40) See Art. **137.**

(41) In most generators the current is alternating, but in special cases the generator is provided with a commutator having two segments, which serves to rectify the current, thus making it pulsating, but always in the same direction.

(42) In the construction of laminated cores, the best quality of soft annealed sheet iron may be used, while in cast cores, the iron is more than likely to be hard, even though a good grade of iron is used, this hardness being caused by the fact that the castings are necessarily thin and the iron is therefore chilled in molding. Another and more important reason is that the production of eddy currents within the core is largely prevented.

(43) The large gear-wheel is corrugated so as to play over the entire surface of the small gear-wheel, which is made much thicker than the large one. Besides this, the driving-gears are on the left-hand instead of the right-hand side of the generator, so as to be as free as possible from the uneven strains produced by the crank in turning.

(44) (*a*) They do not differ at all.

(*b*) There are three bridged circuits in a bridging telephone. One of these contains the ringer or polarized bell, and is usually permanently closed. Another circuit is normally open, and contains the calling generator. This circuit is usually closed automatically upon the turning of the generator crank, so as to throw the generator in parallel with the ringer across the terminals of the instrument. A third bridged circuit exists, containing the secondary winding of the induction-coil and the receiver, this circuit being normally open at the hook switch, but closed when the receiver is removed for use. The local circuit containing the battery, the transmitter, and the primary of the induction-coil is normally open and is identical with that of the ordinary series instrument.

(45) (*a*) With the solid-back transmitter.

(*b*) It has a high and constant electromotive force when in use, has low internal resistance, and can maintain a large current output without polarizing.

(*c*) It is unpleasant to handle on account of the nature of its solutions, which, if spilled, are likely to produce much damage.

(46) (*a*) and (*b*) See Art. **88.**
(*c*) See Art. **89.**
(*a*) See Art. **90.**

(47) (*a*) The Solid-Back transmitter designed by White.

(*b*) By Mr. Anthony C. White.

(*c*) By the American Bell Telephone Company and its licensees, for all purposes, but especially for long-distance work.

(48) No. Coils should be designed with reference to the particular make of transmitter with which they are to be used.

(49) (*a*) See Art. **159.**
(*b*) See Art. **160.**

(50) (*a*) The sine wave.
(*b*) See Arts. **180, 181,** and **182.**

(51) (*a*) See Art. **196.**

(*b*) The ringer is remarkably sensitive; it is easy to adjust and repair; and the fact that the coils and working parts are enclosed within the permanent magnet afford considerable mechanical protection.

(52) (*a*) All joints that are not likely to be taken apart in the future should be soldered, and in soldering, the flux used should contain no acid.

(*b*) Temporary connections are preferably made by means of binding-posts, the permanent connections to the binding-posts being either soldered or firmly clamped between broad copper washers.

(*c*) Flexible joints of this kind are usually made through the hinges of the box, the hinges being provided with spring clips for the prevention of poor contacts.

(53) (*a*) For portable work the dry cell may be used with advantage.

(*b*) They have usually neither recuperative power nor constancy, nor are they in any way so reliable as good Leclanché cells.

(54) The two electrodes bear a fixed relation to each other, there being no relative movement between them. Moreover, the diaphragm is loosely mounted, and carries rigidly attached to its center a chamber containing the two electrodes and the granular carbon.

(55) Those using batteries for the source of calling current, and those using magneto-generators.

(56) (*a*) A generator shunt is a path of low resistance normally closed about the generator armature, thus short-circuiting it. Means must be provided for breaking the shunt when the generator is operated, as otherwise all the current would pass through the shunt without going to line.

(*b*) The presence of the resistance of a generator armature in circuit with the polarized bell is undesirable for several reasons, one of these being that it would cut down the in-coming calling currents designed to operate the polarized bell. Another reason is that when several instruments are used in series in a circuit, it would become necessary to talk through the generator armatures of all the instruments that are not in use, thus greatly reducing the efficiency of transmission. Still another reason is that when the generator armature is short-circuited, it is much less liable to injury by lightning or strong currents from other sources than if it were left permanently in circuit.

(57) (*a*) From 60 to 75 volts.

(*b*) About 600 ohms, No. 35 or No. 36 B. & S. gauge silk-covered wire being used for the winding.

(*c*) About five.

(58) See Art. **199.**

(59) (*a*) See Art. **233.**
(*b*) See Art. **234.**

(60) Variations of magnetic reluctance (or electromotive force), resistance, and capacity.

(61) Where the granules are not of the same size, they settle into a compact mass, the smaller ones settling down between the larger ones. Where moisture enters the carbon chamber from the breath or from other sources, packing is very likely to occur. Sometimes several granules become wedged tightly between the two electrodes in such manner as to hold them farther apart than when in their normal position.

(62) Because the amount of energy available in the ordinary battery is not sufficient to actuate one of these bells over very long circuits. Vibrating bells are not extremely sensitive, and, moreover, the make-and-break contact between the armature and the point against which it normally rests is likely to give trouble on account of corrosion.

(63) In tempering steel, the bar should be heated slowly, in order that it may be at a uniform temperature throughout. Care should be taken in quenching the bar that the limbs shall be held a proper distance apart and that the means for holding it shall not prevent the water from coming into contact with its entire surface. The water should be kept cool and, preferably, running.

(64) (*a*) In a series telephone, the cores of the polarized bell are usually comparatively short and wound with No. 31 wire to a resistance of from 60 to 120 ohms. The polarized bells for bridging telephones are usually provided with long cores and are wound to a much higher resistance, usually 1,000 or 1,200 ohms.

(*b*) Series telephones are placed in series in the line-wire, and therefore when several of them are used on one line, the voice currents set up by one instrument are forced to pass through the bell-magnets of all the other instruments on the line that are not in use. For this reason, a low coefficient of self-induction is desirable. On the other hand, bridging telephones are connected in multiple across the two sides of the circuit, and unless the magnets of the polarized bells possessed a high coefficient of self-induction, they would form serious leaks for the telephone currents, and thus greatly impair the efficiency of transmission.

(65) (*a*) The functions of the hook switch are, in the ordinary telephone, to alternately bring in circuit the talking and the calling apparatus. When the instrument is not in use and the receiver is upon the hook, the calling apparatus is connected with the line circuit; while, when the receiver is removed from the hook for use, the calling apparatus is cut out, and the talking apparatus is connected with the line. A further function is to maintain the local circuit containing the transmitter battery open at all times except when the instrument is in use.

(*b*) It was found in the early days of telephony that people could not be relied upon to perform the various changes in the circuits. They would constantly forget to disconnect the talking apparatus from the line when through using the telephone, thus leaving the calling apparatus inoperative, so that no call could be received from a distant station. Moreover, the transmitter batteries were frequently ruined by virtue of being left in a closed circuit for considerable lengths of time. The automatic hook switch effectually remedied all these difficulties by performing these various switching operations without the volition of the user.

(66) (*a*) Walnut is the most common, and, all things considered, the most desirable, wood. Oak, however, is being largely used, while mahogany, cherry, sycamore, and many other varieties of wood are used as occasion demands.

(*b*) See Art. **236** and Figs. 94 and 95.

(*c*) When the box is removed, the batteries are entirely exposed and may be readily repaired or renewed. There is no chance for the collection of dirt in the bottom of the battery-box, all parts being easily accessible. The resting of the elbow of the user of the telephone upon the lid of the battery-box does not tend to loosen it as in many forms of instrument, but rather to tighten it—an obvious advantage.

(67) (*a*) and (*b*) See Art. **40.**

TELEPHONY.

(PART 2.)

(1) (*a*) A telephone exchange is a combination of a number of telephones with their line circuits and switching devices, by means of which any telephone may be connected with any of the other telephones.

(*b*) Grounded-line systems, common-return systems, and metallic-circuit systems.

(2) By means of electro-mechanical annunciators or drops, these being provided with a shutter adapted to be released by a catch operated by an electromagnet placed in the line circuit. See Art. **14.**

(3) No; all the line-wires are connected to a common wire, which is itself grounded.

(4) Drops must be so constructed as not to be liable to get out of adjustment. Both poles of the electromagnet should, if possible, be presented to the armature. The armature should come near to the pole-pieces without touching them, and all iron used in the construction of drops should be of the softest possible grade. It is especially desirable that the drops shall occupy but little space, and that they may be easily removed from and replaced in the switchboard when repairs are necessary.

(5) Because all the parts are rigidly mounted together by metal, which will not be affected to any practical extent by changes in temperature or moisture.

(6) By means of a split conical bushing, having an internal diameter slightly smaller than the external diameter of the cord, and adapted to fit tightly in a hole bored in the framework of the switchboard. See Art. **64** and Fig. 22.

(7) It is impossible to prevent induction between the various lines, and, moreover, earth-currents due to the return circuits of electric railways or to other causes produce sounds in the telephones which frequently render a conversation impossible.

(8) (*a*) To attract the attention of the operator at night, when her presence is not required at all times at the board.

(*b*) The drop, in falling, closes an auxiliary local circuit containing a battery and a vibrating bell. The closure of this circuit causes the bell to ring until the operator restores the shutter after answering the call. See Art. **15.**

(9) (*a*) In the grounded system, the return side of all circuits is made through the ground; in the common-return system, the return is made through a common wire.

(*b*) Yes.

(10) First, the drop may be cut out of circuit during conversation; second, the drops, if left in circuit, may be placed far enough apart not to affect each other; and third, a magnetic shield may be placed around the drop.

(11) The Warner drop, the American Electric Company's tubular drop, and the Western Telephone Construction Company's tubular drop.

(12) (*a*) See first part of Art. **65** and Figs. 22 and 23.
(*b*) See latter part of Art. **65** and Fig. 24.

(13) (*a*) The return circuit of all lines is made through a common wire instead of through the ground, as in the grounded system.

(*b*) The troubles due to earth-currents may be entirely eliminated in the common-return system, and the inductive troubles may be almost eliminated. See Art. **9.**

(14) By inserting an answering plug into the spring-jack belonging to that line, and then switching her telephone set into the cord circuit of the plug used.

(15) (*a*) See Art. **25.**

(*b*) The metallic-circuit jack is provided with two contacts adapted to register with two corresponding contacts on the connecting plug. The grounded or common-return jack is provided with but one contact adapted to register with the plug.

(16) See Art. **39.**

(17) (*a*) See Art. **53.**

(*b*) It is entirely self-contained, all parts being mounted on a single brass bracket. It is, moreover, very sensitive and easily adjusted. There is but little tendency to cross-talk between drops of this kind, because the outside field set up by one coil tends to neutralize that set up by the other.

(*c*) They occupy much more space than many other forms of drops.

(18) One so arranged that the shutter or target will be automatically restored by the insertion of a plug in the jack. See Art. **68.**

(19) (*a*) The use of a complete metallic circuit for each telephone-line.

(*b*) In metallic-circuit systems, a separate pair of wires are used for each line, while in the common-return system, the return side of each circuit is made through a wire common to a large number of circuits.

(20) See Arts. **16** and **17.**

(21) See Arts. **27, 28,** and **29.**

(22) See Arts. **44, 45,** and **46.**

(23) (*a*) See Art. **61.**
(*b*) See Art. **62.**

(24) (*a*) Electrically restoring and mechanically restoring drops.

(*b*) The American Bell Telephone Company uses an electrically restoring drop, one of these being shown in Figs. 25 and 26. Examples of the mechanically restoring drops are found in those of the Western Telephone Construction Company, illustrated in Figs. 27 and 28, and those of the American Electric Telephone Company, shown in Figs. 29 and 30.

(25) (*a*) Manual and automatic.

(*b*) To the manual class.

(*c*) The automatic switchboards involve the use of very complicated mechanism, the complication increasing very rapidly as the number of subscribers is increased. Up to the present time, automatic switchboards have not been used except for small exchanges, owing to this complication.

(26) (*a*) See Art. **18.**

(*b*) See Arts. **19** and **20.**

(27) A drop left connected with the circuit of two subscribers' lines during the time while they are connected for conversation. When either subscriber rings off, the current will pass through the winding of the clearing-out drop, thus causing it to display its signal.

(28) The tubular shell in which the electromagnet of the drop is enclosed forms, with the core and armature, a practically complete circuit for the magnetic lines of force set up by the currents flowing through the coil. This prevents the formation of an extra field of force outside of the shell of the drop, and therefore practically no lines of force pass from one drop to another.

(29) The strands of one conductor frequently pass through the insulation and make contact with those of the other conductor, thus short-circuiting the cord. Again, the flexible conductors within the cord frequently break, thus leaving the cord circuit open. One particular cause of breakage in cord circuits is the kinking of the cord just at the point where it emerges from the handle of the plug. This is usually prevented by reinforcing the braiding of the cord at that point.

(30) (*a*) See Art. **67.**
(*b*) See Art. **70.**

(31) The shutter, when released by a call coming in over the line, falls directly in front of the jack. When an operator inserts a plug into the jack, the shutter is lifted by it until it is again caught by the armature rod, being thus set automatically for the reception of another call.

(32) The operator's telephone circuits terminate in springs adjacent to the line springs in the jacks. Enlargements are provided on the switchboard plugs by which, when a plug is partially inserted, the line springs are pressed into engagement with the operator's springs, thus connecting the operator's circuit across the cord circuit.

(33) See Art. **135.**

(34) See Arts. **123** and **124.**

(35) (*a*) In the series-multiple switchboard, one side of the line circuit passes in series through the spring contacts of all the jacks belonging to that line. In the branch-terminal system, the jacks are usually of the open-circuit type, and are connected to the line circuit in multiple instead of in series.

(*b*) In the series-multiple switchboard, the liability to loose contacts in the spring-jacks is very great, there being a large number of such contacts connected in series in each line. It is also difficult to obtain a proper balance between the two sides of the line, and, moreover, the system does not lend itself readily to the use of self-restoring drops. In the branch-terminal board, the possibility of poor contacts in a jack causing trouble at any other jack is entirely obviated. The balance of the line is always maintained and the use of self-restoring drops is an easy matter.

(36) When the shutter falls, a projection upon it falls in front of the opening in the jack. This projection is engaged by a collar on the plug, when the plug is inserted into the jack, this collar serving to raise the shutter to its normal position. If the shutter falls while the plug is inserted in the jack, the projection on the shutter falls in front of the collar on the plug, so that the withdrawal of the plug will again raise the shutter to its normal position.

(37) The terminals of the calling generator are connected to springs lying adjacent to the line springs of the jack. The arrangement is such that when the plug is pushed to its fullest extent into the jack, the line springs are brought into engagement with the generator springs, thus sending a calling current to the line of the subscriber.

(38) (*a*) See Arts. **110** and **111.**

(*b*) It renders the subscriber's telephone set cheaper and more compact because of the absence of the magneto-generator. It further makes possible the automatic signaling between the subscriber and the central office, thus simplifying the work on the part of the subscriber in obtaining a connection.

(39) See Art. **126.**

(40) See Art. **138.**

(41) See Art. **80.**

(42) First, the use of divided switchboards, the connections between subscribers on different boards being brought about through local trunk lines; second, the use of multiple boards, in which every subscriber has a line terminal on every section of the switchboard.

(43) The *B* operators attend to the first part of a connection between two subscribers by inserting trunk-line plugs into the jack of a line upon which a call is indicated. This transfers the line circuit to an *A* operator's board. The *A* operator listens in on the line to determine the number of the call wanted. Having done this, she instructs a

B operator at the board on which the line of the subscriber called for terminates, as to the number of the line desired, and completes the connection to the board of that subscriber through another trunk line. This *B* operator then completes the connection by inserting the trunk-line plug leading from the *A* operator's board into the jack of the subscriber called for. See Art. **109.**

(44) (*a*) By means of the multiple board any operator can connect any two subscribers on the entire board without the assistance of any other operator, while in all the transfer systems, at least two operators must take part in most of the connections.

(*b*) Its great complexity.

(45) (*a*) See Art. **148.**

(*b*) The auxiliary ring on the plug serves to connect the test wire and rings belonging to the jacks of a line to the ground, when a plug is inserted into any jack on that line. This makes the potential of all the test rings on that line the same as that of the ground, so that a click will be heard by an operator at another board, in testing the circuit. See Art. **148.**

(46) (*a*) See Arts. **83** and **84.**

(*b*) See Art. **84** and the last paragraph in Art. **80.**

(47) The Cook-Beach transfer system, the Western multiple-transfer system, and the express system.

(48) See Arts. **117** and **118**; also Fig. 45.

(49) Each line terminates in a spring-jack on each section of the board; thus, if there are 30 sections of the board, each line will have 30 spring-jacks, one on each section.

(50) See Arts. **141, 151,** and **153.**

(51) See Arts. **86** and **87.**

(52) (*a*) See Art. **100.**

(*b*) Because several transfer plugs are connected in multiple to a single local trunk line.

(*c*) No; the term multiple board refers to the multiple connection of spring-jacks to a subscriber's line rather than to the connection of plugs to the transfer circuits.

(53) See Art. **122.**

(54) Each line is provided with a spring-jack on each section of the board. From this it follows that any line may have a connection made with it at any one of the sections. In order to prevent a simultaneous connection with the same line at two or more sections of the board, means are provided whereby the first connection that is made with the line will establish certain conditions which will indicate to other operators that that line is in use.

TELEPHONY.

(PART 3.)

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(1) All batteries and generators will be located at one point, easy of access, instead of being distributed at points extending over a wide area. The cost of maintenance will therefore be greatly reduced and the cost of the subscribers' telephone sets also reduced to a minimum. The subscribers' sets will be rendered much more compact, and the absence of liquid cells will obviate all trouble due to spilling and evaporation of the electrolyte. Moreover, the common-battery systems lend themselves readily to automatic signaling. In general, the whole plant will be made cheaper in first cost and in subsequent maintenance. On account of the supervisory signals, the operator's time is economized to such an extent that she can attend to a larger number of subscribers. In the latest boards she attends to 140, instead of 75, or even 100, as is the case in previous multiple boards.

(2) The Dean system uses the induction-coil at the subscriber's station, the secondary of which is connected in the line circuit, while the primary is connected with the transmitter in a local circuit. The common battery in the Dean system is bridged between the center point of an impedance coil and ground, while in the systems of Stone and Hayes, the battery is bridged across the two sides of the line circuit.

(3) (*a*) See Art. **14** and Fig. 11.

(*b*) See Arts. **15** and **16.**

(4) (*a*) No. 22 B. & S. gauge, tinned, copper wire insulated with two wrappings of silk and one of cotton, or the wool-insulated flame-proof wire.

(*b*) In order to facilitate soldering to the wire at any point at which it may be cut.

(5) A sneak current is a current from some foreign source that finds its way over a telephone-line, and is of such strength as not to render its presence apparent by the ordinary signs. Its danger lies in the fact that if it is allowed to pass through a switchboard or telephone coil for some length of time, it will develop enough heat in that coil to char and ruin the insulation, and perhaps start a fire. See Art. **40.**

(6) By an electric motor, belted or directly connected to the shaft of the generator; by a water-motor, driven from the city mains; by hand; and by placing it in some power-house where it may be belted to a constantly revolving shaft, the current being led from it to the telephone central office by means of a special circuit.

(7) (*a*) The first attempt involved the placing of the transmitter battery directly in series in the cord circuit at the central office.

(*b*) This arrangement had the disadvantage of requiring a separate battery for each cord circuit, and also the further disadvantage of making it necessary for the transmitter to vary the resistance of the entire circuit formed by the two connected lines instead of the resistance of a local circuit.

(8) (*a*) See Arts. **8** and **9.**

(*b*) To maintain the supply current of the battery as nearly steady as possible, and also to prevent the short-circuiting of the voice currents from one side of the line-wire to the other.

(9) (*a*) Supervisory signals are signals associated with the cord circuit and adapted not only to take the place of the clearing-out drops in the older systems, but also to keep the operator at all times informed as to the condition of the subscriber's line.

(*b*) They sometimes consist of magnetic annunciators, but are more frequently formed of miniature incandescent lamps.

(10) (*a*) See Figs. 17 and 18.

(*b*) In the proper method, the thread lies close to the cable and does not readily loosen when cut, while in the improper method, the thread stands out from the cable, and if cut, a considerable length will become untied.

(11) To allow at any time a rearrangement of the line circuits with respect to the switchboard and other terminals. Also to facilitate the making of the various connections in the wiring of an exchange.

(12) For furnishing calling current and also for charging storage-batteries.

(13) See Art. **92.**

(14) (*a*) The lamp is included directly in the circuit of the line with a battery. The subscriber's station is so arranged that while the telephone is upon its hook, the line circuit will either possess a very high resistance or be open entirely, while when the receiver is removed from its hook, a low-resistance path will be offered, which will allow enough current from the battery to flow through the line to illuminate the signal. See Art. **11.**

(*b*) See Art. **12.**

(*c*) The only advantage is in its simplicity.

(*d*) In exchanges whose lines are almost entirely underground.

(15) In one method, the supervisory signals are included directly in series in the cord circuit. In this case, they are usually magnetic annunciators whose shutters are raised by the current when flowing from the common battery through the cord circuit, and dropped when this current ceases to flow, owing to the subscriber hanging up his receiver. The other method is to include directly in the cord circuit the winding of a relay adapted to be operated by the current from the common transmitter battery, as just described; the armature of this relay, however, controls a local circuit, which circuit includes a battery and the supervisory signal itself, this being in the form of a miniature lamp. This latter arrangement is perhaps the most common in large exchanges. See Art. **16** and Fig. 11, also Art. **17** and Fig. 12.

(**16**) The acid tends to corrode the wire and sometimes eats it entirely off, thus opening the circuit. Besides this, where acid is used it discolors the woodwork and sometimes the metal parts with which it comes in contact, and thus presents an unsightly appearance. It is also fatal to good insulation.

(**17**) See Art. **55.**

(**18**) (*a*) To prevent the storage-battery from being short-circuited by the generator armature winding should the generator stop for any reason.

(*b*) See Art. **60.**

(**19**) (*a*) See Art. **5.**

(*b*) In order to prevent cross-talk.

(*c*) In order that the self-induction of these coils may not interfere with the voice currents. Impedance coils form a barrier through which it is difficult for rapidly fluctuating currents to pass. Therefore the impedance coils are bridged across the talking circuit instead of being connected in series in it.

(**20**) A relay is included directly in the line circuit in series with the battery. The arrangement is such at the subscriber's station that a high-resistance or an open circuit is maintained in the line while the receiver is on the hook, but a low-resistance circuit is interposed between the two sides of the line when the receiver is removed from its hook. The closure of this low-resistance circuit serves to operate the relay. In the local circuit of the relay is a lamp signal in series with a battery of proper strength for illuminating the signal, so that upon the operation of the line relay, the lamp signal is illuminated. See Art. **13.**

(21) A line will test "busy" whenever a plug is connected with it at a board other than that at which the test is being made. This is because one terminal of the testing battery *B'* is connected, through the wire *5*, lamp *M* or *M'*, wire *9* or *10*, and thimble *u*, with the test rings *d* belonging to that line, thus raising all the test thimbles on that line to a potential above that of the ground. The line will also test "busy" as soon as a subscriber removes his receiver from its hook, because the operation of the lamp-signal relay *C* will connect one terminal of the battery *B'* with all the test thimbles through the wire *5* and coil *m*, thus bringing about the same result as before. See Art. **22.**

(22) It consists usually of three metallic plates mounted close together but insulated from each other. Each plate carries a binding-post. Two of the plates form the terminals of the circuits containing the apparatus to be protected, and to these the line-wires are connected. The other plate is entirely free from all connection with the apparatus and is connected with the ground. The object of this arrangement is to allow high-tension charges coming over the line-wire to jump to earth across the air-gap between the plates.

(23) (*a*) Jumper wires are the wires used in distributing-board work for connecting the terminal of a line on the line side of a board with the corresponding terminal on the switchboard side. See Arts. **46** and **50.**

(*b*) The best wire to use is of No. 22 tinned copper, rubber covered and twisted in pairs. The covering of one wire should preferably be of red rubber and the other of black, in order that the two may be readily distinguished.

(24) Make sure that the positive pole of the battery is connected to the positive pole of the charging generator.

(25) (*a*) See Art. **7.**

(*b*) Repeating coils, each having two windings, are used in the Hayes system, instead of the impedance coils having only one winding, which are used in the Stone system.

(*c*) The repeating coils serve merely as induction-coils to reproduce in one subscriber's line the current undulations set up in the other. The winding of the repeating coil connected with the line of the subscriber who is talking acts as a primary, and induces similar currents in the other winding of the repeating coil, which is connected in the line of the subscriber who is receiving. This latter winding of the repeating coil then serves as a secondary.

(26) A relay adapted to open the circuit of a subscriber's line at a point beyond the spring-jacks, so as to leave the spring-jacks connected with the subscriber's station, but to cut off all apparatus beyond them. The line cut-off relay usually has its magnet included in a local circuit which is completed when a plug is inserted into a jack belonging to its line. See Art. **13** and Fig. 10, also Arts. **17** and **19** and Fig. 12.

(27) In order to economize room, to render the appearance of the wiring as neat as possible, and to facilitate the tracing and handling of the circuits in the future.

(28) One of these consists of a small fuse wire mounted upon a strip of mica adapted to be connected in the circuit containing the apparatus that is to be protected. Strong current coming over the line will melt this fuse and open the circuit. Another form consists of a small coil of German-silver wire wrapped about a small metal spool, into the core of which is soldered, by a drop of low-fusing metal, a small metallic plug. A spring rests against this plug in such manner as to normally hold open a circuit from the line to ground. When, however, a strong current traverses the German-silver wire, sufficient heat is developed to melt this drop of solder, thus releasing the pin and allowing the spring to come in contact with the ground plate, and thus short-circuiting the apparatus and connecting the line with the ground. See Arts. **36** and **38.**

(29) A magneto-generator similar to the ordinary subscriber's generator, but provided with a shaft and grooved pulley by which it may be driven from some source of power. The permanent magnets are sometimes made longer than in the ordinary hand generator, in order to give an increased magnetic field.

(30) Dip a wire from each terminal into a vessel containing acidulated water. Bubbles will arise from each of the wires while the current is flowing, but at a much greater rate from the negative than from the positive terminal.

(31) (*a*) The solution is composed of water and sulphuric acid mixed to a density of 1.2, as indicated by the ordinary hydrometer.

(*b*) The solution should be mixed in an earthenware vessel, and the acid should be poured slowly into the water, the mixture being thoroughly stirred meanwhile.

(*c*) In order to prevent the throwing of the acid in all directions by the sudden formation of steam due to the intense heat generated.

(32) (*a*) A telephone-line having more than two stations upon it.

(*b*) A line having but two stations is a private line, extending from one station to one other station only. A telephone-line running from a central office to two subscribers' stations is a party line, but such a line has in reality three stations on it, the central office being in every sense of the word a station.

(33) (*a*) Series instruments are connected directly in the line-wire, the current passing through them in series.

(*b*) Bridging instruments are connected across the line circuit, so that each instrument forms a leak from one side of the line to the other. Bridged instruments are therefore connected in multiple.

(34) See Arts. **97, 98,** and **99.**

(35) Some are positively polarized, some are negatively polarized, and some are neutral. The positively polarized relays close their local circuits only when traversed by currents in a positive direction, the negatively polarized relays closing their local circuits only when traversed by currents in a negative direction, and the neutral relays serving to break their local circuits when traversed by currents in either direction.

(36) (*a*) At the extremities of all cable wires.

(*b*) First, because when they burn out, no melted metal can be scattered about, and all danger of fire or damage due to the scattering of hot metal is avoided; second, their melting-point is more uniform because air-currents are excluded. See Art. **43.**

(37) See Art. **70.**

(38) (*a*) Selective and non-selective party lines.

(*b*) Selective signaling lines may be classified under the headings of "step-by-step," "harmonic," and "strength-and-polarity" systems. Non-selective party lines may be divided into two classes, "bridged" and "series."

(39) (*a*) See Art. **86.**
(*b*) See Art. **87.**
(*c*) See Art. **88.**

(40) (*a*) A method using mechanisms at each subscriber's station, actuated by step-by-step movements to close a signaling circuit at that station after a predetermined number of current impulses have been sent over the line by a transmitting mechanism at the central office. See Art. **102.**

(*b*) The difficulty of securing good electrical contact between contact points that are necessarily subject to but slight pressure. Moreover, the step-by-step mechanisms are complicated, thus bringing about all the difficulties usually met in complicated apparatus that can receive only limited attention.

(**41**) (*a*) See Art. **116.**

(*b*) Current from the local battery that is shunted around the call-bell at that station. See Art. **119.**

(**42**) Plug switches. See Art. **129.**

(**43**) The best way is to use a motor generator adapted to give the proper amount of current at the proper voltage. Another way is to connect the storage-batteries directly in some lighting circuits of a building, care being taken that that circuit carries about the proper amount of current to charge the batteries. It may be necessary in doing this to use lower voltage lamps upon this circuit. Still another way is to use current from an ordinary incandescent circuit, regulating the current by a proper rheostat, which may conveniently be composed of incandescent lamps. See Art. **71.**

(**44**) See Art. **79.**

(**45**) By winding the switchboard drop to which the party line is connected to a very low resistance, so as to practically short-circuit all the ringers on the line, or by causing the generators to send out currents in one direction only and polarizing the ringers so as to respond only to the currents in the opposite direction. See Arts. **93** and **94.**

(**46**) (*a*) See Art. **104.**

(*b*) It is difficult to secure a good contact between a rapidly vibrating reed and a stationary contact. Great trouble is also experienced in obtaining and maintaining the proper adjustments of the parts.

(**47**) (*a*) Each branch of the line-wire is connected to the line spring of the jack, from which the circuit passes through an anvil upon which this spring normally rests, and through one winding of the switchboard drop to ground through a battery. The two windings of the switchboard drop are in opposite directions, and are connected in multiple with respect to current from the battery in the ground branch.

(*b*) The removal of the subscriber's receiver from the hook automatically grounds one branch of the line-wire for an instant while the hook lever is raising. This allows an excess of current to pass through one winding only of the drop, thus energizing the core and causing the drop to fall in the ordinary manner.

(*c*) Because the current flowing from the battery B' through each winding is equal, and as the two windings are oppositely wound, the magnetic force set up by one of them is neutralized by that set up by the other, thus producing no effect on the core. See Fig. 56.

(48) See Arts. **83** and **88.**

(49) A separate circuit is used for each operator's transmitter, each circuit including the operator's transmitter, the primary of her induction-coil, and about three cells of gravity battery. See Art. **73.**

(50) See Art. **80.**

(51) A system for preventing one subscriber from listening to a conversation being held between two other subscribers, and also for preventing his breaking in upon this conversation either by ringing or otherwise. See Art. **95.**

(52) (*a*) See Art. **107.**
(*b*) See Art. **108.**
(*c*) For four stations on a line.

(53) (*a*) A system adapted for use in small exchanges, and not requiring the attention of an operator. Each station is placed on a separate wire, this wire leading to switching mechanisms at all the other stations. A subscriber, in order to call up and talk with any one station, switches his telephone on to the wire belonging to that station, after which the ringing and talking are conducted in the ordinary manner. The circuits of a simple form of this system are shown in Fig. 57.

(*b*) The intercommunicating system and the speaking-tube system.

(54) (*a*) See Art. **74.**

(*b*) The battery must be of extremely low resistance, as must also the bus-bars to which the various individual transmitter circuits are connected.

(55) (*a*) From 80 to 120 ohms.

(*b*) To about 600 ohms.

(*c*) Low-wound ringer magnets are desirable because they offer less obstruction to the voice currents which must pass through them than if they were high-wound. The high-wound generator armatures are used because sufficient voltage must be generated to ring all the call-bells connected in series. The high resistance and impedance of the generator armature do not affect the talking circuit, because the armatures are, or always should be, cut out of this circuit by the automatic shunt.

(56) By variously combining the two line-wires of a metallic circuit and the ground, four different circuits may be obtained over which currents may be sent in either direction. By sending a current in the proper direction over any one of these circuits, a certain set of relays at one of eight subscribers' stations may be operated to the exclusion of all others. In practice, instead of using eight stations, but six are used, two of the eight possible combinations being reserved for operating the lock-out and releasing mechanisms.

(57) (*a*) See Art. **125.**

(*b*) See Art. **126.**

TELEPHONY.

(PART 4.)

(**1**) It serves to cut down the loudness without destroying the distinctness or the quality of the tone.

(**2**) (*a*) A law set forth by Mr. Preece, of the British Post-Office Department, stating that if the product of the resistance in ohms and the capacity in microfarads of a copper circuit exceeded 15,000, telephone transmission over that circuit would be impossible.

(*b*) Because Mr. Preece probably assigned too low a value to the K. R. product.

(**3**) (*a*) See Art. **14.**

(*b*) Induction from a lighting or power circuit produces in the telephone instruments a humming sound. Induction from telegraph-lines causes the dots and dashes of the telegraphic code to be distinctly audible in the telephone instruments, while induction from other telephone-wires assumes the form of cross-talk, by which conversation carried on over one circuit may be heard on the other.

(**4**) See Art. **219.**

(**5**) One of the most important considerations is the question of securing proper right of way. Directness of the route as well as the character of the soil, configuration of the country, and freedom from obstructions, such as trees and houses, and many others. See Arts. **33** and **34.**

(6) See Art. **40.**

(7) Standard cross-arms vary in length from 3 to 10 feet, and have a cross-section of $3\frac{1}{4} \times 4\frac{1}{4}$ inches. Telephone cross-arms are made in lengths varying from 2 to 10 feet, and have a cross-section of $2\frac{3}{4} \times 3\frac{3}{4}$ inches.

(8) (*a*) Six to eight.

(*b*) Long-handled digging spoon, long-handled, round-pointed shovel, and a combined crow and digging bar. Sometimes post-hole augers are also used to advantage.

(9) To guy stubs placed in the ground at a short distance from the pole, to anchor logs buried in the ground, or to trees or rocks when available. See Arts. **70, 71,** and **72.**

(10) (*a*) One one-thousandth of an inch.

(*b*) A circular mil is a unit of area used in measuring the cross-section of wires. It is equal to the square of the diameter in mils.

(*c*) Because the area of a round wire in circular mils is equal to the square of the diameter in mils.

(11) (*a*) In the electromagnets of the telephone instruments or switchboard.

(*b*) But slightly greater. See Art. **2.**

(12) (*a*) The insulation resistance of a line is the joint resistance of all the leaks from that line to other conducting bodies. See Art. **9.**

(*b*) The insulation resistance per mile is found by multiplying the total insulation resistance of a line by its length in miles.

(13) (*a*) See Art. **16.**

(*b*) That cross-talk was caused by electrostatic induction rather than by electromagnetic.

(14) (*a*) A system in which the return of each circuit is made through a wire common to all the circuits.

(*b*) It avoids all trouble from leakage and earth-currents, and, moreover, relieves to a large extent inductive troubles. See Art. **26.**

(15) (*a*) Norway pine, chestnut, cypress, and white cedar.

(*b*) Pine 6 years, chestnut 15 years, cypress 12 years, and cedar 10 years.

(*c*) White cedar.

(16) The selection of the positions for the poles on the river-banks should be made with due regard to obtaining a firm foundation. After setting the poles, they should be thoroughly guyed in a direction to meet the strain of the long span between them.

(17) (*a*) The usual method is by means of two $\frac{1}{2}$-inch lag-bolts of sufficient length to pass nearly through the pole. A method that is now being used to some extent is to secure the cross-arm in place by means of one or two $\frac{5}{8}$-inch carriage-bolts passing entirely through the cross-arm and pole and secured in place by a nut and washer.

(*b*) The latter method is considered best, because the grain of the pole is not injured so much and the replacing of old cross-arms by new ones is rendered easier.

(18) See Arts **59, 60,** and **61.**

(19) Sometimes of two No. 9 iron wires twisted together, sometimes of a single No. 8 or No. 6 iron wire, and sometimes of a steel rope composed of 7 strands and varying in external diameter from $\frac{3}{32}$ to $\frac{1}{2}$ inch.

(20) $80.808 \times 80.808 = 6{,}529.93$. Ans.

(21) The electrostatic capacity of the line circuit.

(22) Changes in the strength of the earth's magnetic field; earth-currents, due either to natural causes or to the grounding of circuits carrying heavy currents, such as those of railways; electromagnetic induction from other wires;

leakage from other wires; electrostatic induction from other wires.

(23) See Arts. **17** and **18.**

(24) See Art. **27** and Fig. 15.

(25) That they shall have 7-inch tops. Sometimes, however, the circumference 6 feet from the butt is also specified, the standard dimensions being given in Table 2, Art. **36.**

(26) (*a*) So proportioning the heights of the various poles and their location with regard to depressions or elevations in the ground that no sharp vertical bends will occur in the line-wires when stretched.

(*b*) See Art. **45.**

(*c*) Some poles will be subjected to very severe downward strains, while others may be subjected to an upward strain by the line-wires, tending to lift them out of the ground or to pull off the insulators.

(27) (*a*) Cross-arm braces are flat strips of iron $\frac{1}{4} \times 1\frac{1}{4}$ inches in cross-section, and from 20 to 30 inches long.

(*b*) They are used to prevent the cross-arm from twisting in the gain, thus preserving them in a horizontal position.

(*c*) They are usually attached to the pole by a single lag-screw passing through the two braces of one arm. They are attached to the cross-arms by 4-inch carriage-bolts passing entirely through the cross-arm and secured by nuts. Washers should be placed under both the heads and nuts of all bolts.

(28) (*a*) The pole is braced by four pike-poles. The pikes should be stuck in the pole at points about 8 feet from the ground, while the butt ends of the pike-poles are planted in the ground.

(*b*) The filling in should not be done faster than the earth can be properly tamped.

(29) (*a*) To allow access to the lines of cable at frequent intervals, in order to facilitate the drawing in or out of the cable, the splicing and repairing, and also the distribution of wires from the cable.

(*b*) About 400 feet apart.

(*c*) At the corners of the streets and at sharp turns in the conduit.

(30) $\frac{1}{8}$ inch = 125 mils. $125 \times 125 = 15,625$. Ans.

(31) Local capacity is the capacity which is connected with a circuit at one definite point, while distributed capacity is, as its name indicates, distributed throughout the length of a circuit. Distributed capacity is usually caused by the condenser actions between the line-wires themselves or between one of the wires and the ground or other conductors. Local capacity is usually formed by the insertion of a condenser at some point in the circuit. See Art. **4.**

(32) Electrostatic.

(33) There is no known method except to place the wires so far apart that there will be no action between them. Where a large number are to be run in an exchange this is impossible.

(34) One way is to connect the terminal of the grounded line directly to one terminal of the metallic-circuit line, and grounding the other terminal of the metallic-circuit line, as shown in Fig. 16. The other method is by the use of a repeating coil, the two terminals of the metallic-circuit line being connected, respectively, to the two terminals of one winding of the repeating coil, while the terminal of the grounded line is connected with one terminal of the other winding of the repeating coil, the remaining terminal of which winding is grounded. This method of connection is shown in Fig. 19. The only advantage in the method first described is that of simplicity. Its disadvantages are that it serves to unbalance the metallic circuit and to make both circuits subject to earth-currents. The advantages of the second method are that the metallic circuit is not connected with the ground, nor is its balance in any way destroyed. The disadvantages of the repeating coil are that it is sometimes difficult to ring through it, and that the repeating coil is very susceptible to burn-outs.

(35) Where the line is to carry but few wires, and where the financial condition of the company installing the plant will not allow the heavier construction.

(36) (*a*) The butts should be pointed down hill.

(*b*) So that the tops of the poles will have a shorter distance to travel while the pole is being raised.

(37) (*a*) Locust is the best, although oak is much used.

(*b*) The shank of the pin is turned to fit the hole in the cross-arm, and after being driven in, is secured by a nail driven through the cross-arm and pin.

(*c*) By a coarse screw-thread.

(38) (*a*) When the ground is marshy, when for any reason the hole can not be dug to the required depth, or where the pole is to be subjected to some very severe strain, as in dead-ending. See Arts. **64, 65,** and **74.**

(*b*) Of either lumber or cement, as described in Arts. **64, 65,** and **74.**

(39) See Art. **75.**

(40) $\sqrt{10,383.02} = 101.897$. Ans.

(41) See Arts. **5** and **6.**

(42) See Art. **13.**

(43) By transposing the wires at frequent intervals, as described in Arts. **22, 23, 24,** and **25**; also by twisting the two wires of a circuit together, as is done in cable work, thus effecting a complete transposition of the wires every few inches.

(44) (*a*) See Art. **30** and Figs. 17 and 18.

(*b*) So as to render complete the magnetic circuit through the core. The lines of force set up by the currents in the coil, instead of having to complete their paths through the air, as where a straight core is used, follow the iron wires through the entire circuit. This allows a much greater electrical efficiency.

(45) (*a*) Sometimes the poles are impregnated with creosote, sometimes subjected to a process called galvanizing. In this country, particularly, poles are frequently coated for a distance of 6 or 7 feet from the butt with hot pitch.

(*b*) The wind-and-water line is the line around the pole at the surface of the ground, so called because on that line the combined effects of the air and moisture are greatest.

(46) They should be given about three coats of best white lead, in order to prevent moisture from entering the grain of the wood.

(47) (*a*) See table, Art. **55.**

(*b*) The nature of the soil, the height of the poles, the number of wires to be carried, the number of poles to the mile, the frequency of heavy wind or sleet storms, and the side or end strains placed on the poles by the wires in turning corners or in dead-ending.

(48) (*a*) A guy that branches at a point near the pole, one branch extending to the top of the pole and the other to a point at or near the lowest cross-arm.

(*b*) So as to prevent an undue strain occurring in the vicinity of the lower cross-arm. See Art. **66.**

(49) (*a*) By different gauges, referring to the various sizes by number; usually the larger the wire the smaller the number.

(*b*) The Brown & Sharp, or American, gauge.

(*c*) The Birmingham wire gauge.

(50) The cross-sectional area of the wire is doubled as the gauge number is diminished by 3, and is halved as the gauge number is increased by 3. See Arts. **83, 84, 85,** and **86.**

(51) See Art. **87.**

(52) See Art. **97.**

(53) (*a*) "Extra Best Best," "Best Best," "Best," and "Steel."

(*b*) See Art. **107.**

(54) Because if it is drawn too tight in warm weather, there will be no room for contraction in its length during the cold weather, and it is therefore likely to break by its own efforts to contract.

(55) (*a*) Dry-core cables and saturated-core cables.

(*b*) Dry-core cables have a very low specific inductive capacity and a very high insulation. They are, however, very susceptible to injury by moisture, and should therefore only be used where proper means are at hand for testing and repairing them. The saturated-core cables have a considerably higher electrostatic capacity than dry-core cables and have the advantage of not being so susceptible to moisture, and are therefore more desirable for use in short lengths, where they can not be properly inspected and maintained.

(56) See Arts. **162** and **163.**

(57) (*a*) See first paragraph of Art. **179.**
(*b*) See last paragraph of Art. **179.**

(58) (*a*) See Art. **189.**
(*b*) See Art. **190.**

(59) (*a*) Because of the necessarily high electrostatic capacity of the cables.

(*b*) The improvement of the transmission circuit rather than that of the instruments.

(60) (*a*) See Art. **221.**

(*b*) See Art. **222.**

(61) $324 \times 1{,}000 \times \frac{1}{10} = 32{,}400$. Ans.

(62) (*a*) The weight of a wire of uniform size, 1 mile long, and having a resistance of 1 ohm.

(*b*) See Art. **93.**

(63) (*a*) At least $2\frac{1}{2}$ times its weight per mile.

(*b*) See Art. **101.**

(64) (*a*) It was not properly galvanized and should be rejected.

(*b*) Because the zinc coating was removed by the action of the solution, allowing the copper in the solution to deposit directly upon the iron. See Art. **108.**

(65) (*a*) See Arts. **124** and **125.**

(*b*) The solder should be applied at the center of the joint only, for the heat that is necessary to cause the solder to flow is likely to weaken the line-wire, and it is better to weaken it where it is double than at the ends of the splice, where it is single.

(66) (*a*) Tests should be made to determine whether or not moisture has entered the cable end.

(*b*) The test is made by dipping the end of the cable into hot paraffin, or by cutting off a short portion of the cable and immersing it in hot paraffin. If bubbles arise from the hot liquid, moisture has entered. The cable should then be cut back or dried out by means of a torch until all moisture has been removed.

(67) See Arts. **164** and **165.**

(68) (*a*) It is proof against all chemical action and will last indefinitely unless destroyed by mechanical means. It is a good insulator, is cheap, and easily laid.

(*b*) The single-duct section.

(*c*) Because it is easier to manufacture and more readily handled.

(69) A pole is located near the manhole and a wrought-iron pipe is led from the manhole up the side of the pole, the cable passing up through this pipe to a terminal box located on the pole. The cable wires are connected, by means of the terminal box, with the overhead circuits.

(70) The magneto testing set, the telephone receiver and battery, and the galvanometer detector.

(71) The Wheatstone bridge.

(72) See Art **236.**

(73) $\frac{869 \times 100}{885} = 98.19\%$. Ans.

(74) See Table 11 and Art. **109** for exact resistance. A No. 8 wire has a diameter of 165 mils. Using the first formula in Art. **104,** we have

Approximate resistance per mile =

$$\frac{360,000}{165^2} = \frac{360,000}{27,225} = 13.22. \quad \text{Ans.}$$

(75) See Arts. **115** and **116.**

(76) (*a*) The wires are bunched into cables. See Art. **128.**

(*b*) By using metallic circuits only, and twisting the two sides of each circuit together, thus forming a separate pair.

(*c*) No; if any considerable lengths of cables are used on the grounded-circuit plan, there will be a large amount of cross-talk.

(77) See Arts. **153, 154,** and **155.**

(78) In order to allow sufficient length for making necessary splices in the future.

(79) By means of a mandrel drawn through the conduit during the process of laying.

(80) (*a*) At the point where the earth-current flows from the cable sheath to the earth or other conductors.

(*b*) See Arts. **197** and **198.**

(81) Because the electrostatic capacity of long circuits is frequently high enough to allow enough current to pass into and out of the circuit to ring the polarized bell of the testing set, thus producing the same effect as if the circuit were continuous, or as if a ground or cross existed.

(82) (*a*) The Thomson galvanometer and the D'Arsonval galvanometer.

(*b*) The Thomson galvanometer is by far the most sensitive, and therefore suitable where tests of the greatest accuracy are to be made. It, however, has the disadvantage of being so sensitive as to be affected by slight external magnetic disturbances, and is therefore suited only for laboratory work where it can be properly shielded from such disturbances. The D'Arsonval galvanometer is the most satisfactory instrument for general work. It is quite sensitive, and is never affected at all by external magnetic fields. The suspension of the needle is not so delicate as in the Thomson, thus making it easier to set up and less liable to injury.

(83) See Art. **242.**

(84) Using the formula $W = \frac{d^2}{62.5}$, we have

$$\text{Weight} = \frac{71.962^2}{62.5} = 82.85. \quad \text{Ans.}$$

(85) Copper wire possesses about six times as great a conductivity as iron, is non-magnetic, and therefore line circuits constructed of copper possess very much less impedance than when constructed of iron. Moreover, the fact that a copper wire will be much smaller than an iron wire having the same resistance, makes the electrostatic capacity of the copper wire much smaller than that of the iron wire, therefore giving a lower value to the product of the resistance and capacity. Besides this, copper is practically indestructible under ordinary atmospheric conditions, while iron rapidly corrodes. See Arts. **112** and **113.**

(**86**) (*a*) The coil of wire is placed on a reel on a hand-barrow, and one end of it is fastened to a point at the beginning of the section to be strung. The hand-barrow is then carried along, the wire being paid out from the reel as it proceeds. The wire is then lifted up to the cross-arms on each pole, after which it is pulled taut and tied.

(*b*) See Art. **118.**

(**87**) Its advantages are that its insulation is very high and not susceptible to the action of moisture. It is therefore well adapted to all places where a very high insulation must be maintained in the presence of moisture. Its disadvantages are that owing to the specific inductive capacity of rubber, cables with this form of insulation possess a high electrostatic capacity.

(**88**) For connecting the wires of a cable to other wires without allowing moisture to enter the insulation at the cable end.

(**89**) (*a*) The creosoted wood or pump-log conduit.
(*b*) The fact that it will probably eventually decay.

(**90**) See Art. **183.**

(**91**) The danger point or points should be located by means of tests with a voltmeter, and at these points the cable sheath should be bonded to the neighboring conductors to which the current is flowing. See Arts. **198** and **199.**

(**92**) It is extremely sensitive, and if a watch-case receiver is used with a head-band, it allows the freedom of both the user's hands. It is, moreover, very light and therefore easily carried.

(**93**) A deflection is first obtained through a known resistance for the given battery, and from this the constant of the galvanometer is computed; after this, the deflection produced by a current from the same battery through the insulation resistance to be measured is noted, and by comparing this deflection with that through the known resistance, the insulation resistance may be computed. See Art. **229**.

(94) See Art. **243**.

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NOTE.—All items in this index refer first to the section (see the Preface) and then to the page of the section. Thus, "Battery-box 1 181" means that battery-box will be found on page 181 of section 1.

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